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Economic Analysis of Management Alternatives Proposed for the Commercial Vermilion Snapper Fishery in the Gulf of Mexico

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Abstract: *This report documents the bioeconomic model developed to analyze management alternatives proposed in 2004 for the commercial vermilion snapper fishery in the Gulf of Mexico. The model uses logbook data from 2000-2002 to simulate the effects of proposed management alternatives on catches of vermilion snapper and the profitability of commercial fishing trips during a 10-year rebuilding period for vermilion snapper. A biological surplus production model updates population biomass at the beginning of each simulated year based on aggregate commercial and recreational fishing-related mortality during the previous year. Changes in biomass are used to update catch per trip during the current year. The present value of fishing incomes net of trip costs for each management alternative was compared to the present value for the status quo to determine if the proposed alternatives are expected to generate net benefits or losses to commercial fishermen over the 10 year study period.*

Introduction

The National Marine Fisheries Service declared the vermilion snapper (*Rhomboplites aurorubens*) resource in the Gulf of Mexico to be overfished, and that additional management was required to rebuild the population to biologically acceptable levels. Amendment 23 to the Reef Fish Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico (GMFMC 2004) considers a wide range of management alternatives for the commercial and recreational fisheries. This report describes the economic analysis of proposed management alternatives for the commercial vermilion snapper fishery. A companion report by Carter (2004) describes analyses of proposed management alternatives for the recreational fishery.

Historical Trends in Landings and Value

Historical data about commercial landings and dockside revenues are presented for the 1984-2002 period.[1] Vermilion snapper probably were landed prior to 1984, but the data reporting system may have lumped vermilion and other red colored snappers with true American red snapper (*Lutjanus campechanus*). Since 1984, the National Marine Fisheries Service (NMFS) and state agencies have provided better species identifications for the commercial catch.

Between 1984 and 2002, commercial landings of vermilion snapper ranged from a high of 2.7 million pounds (whole weight) worth $4.4 million in 1993 to a low of 1.5 million pounds worth $2.8 million in 2000 (Fig. 1). Schirripa (1998) noted that peak landings in 1993 and 1994 were associated with high incidences of juvenile vermilion snapper in the NMFS bottom trawl survey two and three years earlier, and that catches of vermilion snapper probably would decline in the late 1990s because the incidence of juveniles in the bottom trawl survey had declined.

Dockside revenues generally displayed the same trend over time as commercial landings (Fig. 1). Since revenues and pounds landed fluctuated in the same direction, we conclude without conducting a formal econometric analysis that ex-vessel demand is price elastic. The policy implication is that regulation that reduces industry landings in the short-term is expected to reduce dockside revenues also. Conversely, dockside revenues are expected to increase over time if regulation successfully increases biomass and landings.

Vermilion snapper occur throughout the Gulf of Mexico, but primarily in the northern regions where it represents the second most important source of revenue, after red snapper, for

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[1] Industry landings and dockside value were obtained on October 1, 2003 from the Accumulated Landings System maintained by the NMFS Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149. Landings and revenues are collected monthly from dockside dealers.

commercial reef fish fishermen. Vermilion snapper are landed primarily with vertical hooks and lines in the northern Gulf, although incidental catches are reported throughout the Gulf with vertical lines, bottom longlines, fish traps and trolling lines.

Logbook data for 1993-2002[2] provided information about the extent to which vermilion snapper were primary or secondary sources of trip revenue. Fishing trips were classified as targeting a particular species if revenues from that species were greater than revenues from any other individual species.[3] Vermilion snapper were landed on an average of 4,065 trips per year, with less than 30% of them classified as targeted vermilion snapper trips (Fig. 2). Vermilion snapper were caught frequently by boats on red snapper trips in the northern Gulf and grouper trips in the eastern Gulf, but the volume of secondary catch accounted for only 25% of the total harvest of vermilion snapper in 2002 (Fig 3). Nevertheless, the amount of secondary catch associated with red snapper trips has increased over time, probably because the timing of regulated open seasons for red snapper has evolved to allow more fishing between April and September when vermilion snapper are most available for capture. The following analysis of proposed management alternatives for the commercial vermilion snapper fishery explicitly accounts for targeted and secondary catches of vermilion snapper.

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[2] Fishermen with federal permits to participate in the commercial reef fish fishery are required to report pounds landed by species on logbook sheets for each trip. Logbook data were obtained on September 25, 2003 from the NMFS Southeast Fisheries Science Center, 75 Virginia Beach Drive, Miami, FL 33149.

[3] Fishermen do not report prices or revenues on their logbook sheets. Therefore, trip revenues were approximated as reported landings from individual logbook reports multiplied by average monthly prices for each species as calculated from the NMFS Accumulated Landings System.

Proposed Management Alternatives

A history of management relating to vermilion snapper is presented in amendment 23. Vermilion snapper are managed in federal waters by the Gulf of Mexico Fishery Management Council (hereafter referred to as the Council) as one of many demersal species included in its Reef Fish Fishery Management Plan for the Reef Fish Resources of the Gulf of Mexico (hereafter referred to as the FMP). The original FMP, implemented in November 1984, and its amendments include restrictions on commercial and recreational fishing in a variety of ways. Three amendments directly regulate the harvest of vermilion snapper. In January 1990 (55 *Federal Register* 2078; January 22, 1990), amendment 1 to the FMP implemented an 8 inch (total length) minimum size limit for vermilion snapper landed by commercial and recreational fishermen. In January 1997 (61 *FR* 65983; December 16, 1996), amendment 12 created an aggregate bag limit of 20 reef fish per person per trip, including vermilion snapper, for recreational fishermen. In January 1998 (62 *FR* 67714; December 30, 1997), amendment 15 increased the minimum size limit for vermilion snapper to 10 inches. Other amendments may have indirectly affected the harvest of vermilion snapper by restricting fishing activities or harvests of other species, such as red snapper, in the reef fish management unit.

Porch and Cass-Calay (2001) provided a new stock assessment for vermilion snapper based on data from 1986-1999, and concluded that biomass was less than the minimum spawning stock threshold (MSST) and that fishing mortality exceeded the maximum fishing mortality threshold (MFMT). The NMFS notified the Gulf Council that the stock was overfished and that overfishing was occurring, and that additional biological protection was required.

Amendment 23 proposes management alternatives to eliminate overfishing and rebuild the vermilion snapper stock to acceptable biological levels within 10 years, starting in 2004. The proposed alternatives are listed in Table 1, and include trip limits, minimum size limits, quotas, and seasonal closures. The Council established a 10-year stepped catch rebuilding strategy in which the total allowable catch (TAC) would remain constant for the first 4 years of the rebuilding period, and then would be increased every 3 years provided that stock recovery proceeds as planned. The TACs associated with the rebuilding plan define the time paths of commercial harvests with quota management. The TACs represent desired harvest levels for other forms of management, such as trip limits, minimum size limits and seasonal closures, although actual catches would not be constrained to the TAC. Proposed trip limits and quotas are expressed on a whole weight basis.

Table 1. Proposed management alternatives for the commercial vermilion snapper fishery.

Label	Type	Description of Management Alternative
Alternative 1	Status Quo or No Action	Com: Do not reduce the commercial harvest of vermilion snapper. Maintain a 10 inch, total length, minimum size limit. Rec: Do not reduce the recreational harvest of vermilion snapper. Maintain a 10 inch, total length, minimum size and aggregate bag limit of 20 fish.
Alternative 2	Trip Limit	Com: The commercial trip limit for vermilion snapper will be 1625 pounds, whole weight (an expected 25.2 percent initial harvest reduction). Rec: The recreational bag limit for vermilion snapper will be 2 fish (an expected 30.0 percent initial harvest reduction).

Alternative 3	Minimum Size Limit	Com: The minimum size for commercially caught vermilion snapper will be 12 inches, total length (an expected 27.0 percent initial harvest reduction). Rec: The minimum size for recreationally caught vermilion snapper will be 11 inches, total length, and the bag limit will be10 fish (an expected 21.5 percent initial harvest reduction).
Alternative 4A	Trip Limit and Minimum Size Limit	Com: The minimum size for commercially caught vermilion snapper will be 11 inches, total length, and the trip limit for vermilion snapper will be 2300 pounds, whole weight (an expected 25.8 percent initial harvest reduction). Rec: The minimum size for recreationally caught vermilion snapper will be 11 inches, total length, and the bag limit will be 7 fish (an expected 25.6 percent initial harvest reduction).
Alternative 4B	Trip Limit and Minimum Size Limit	Com: The minimum size for commercially caught vermilion snapper will be 11 inches, total length, and the trip limit for vermilion snapper will be 2250 pounds, whole weight (an expected 26.3 percent initial harvest reduction). Rec: The minimum size for recreationally caught vermilion snapper will be 11 inches, total length, and the bag limit will be10 fish (an expected 21.5 percent initial harvest reduction).
Alternative 5	Quotas	Com: The initial annual commercial quota in whole weight for vermilion snapper will be 0.989 million pounds based on a 10-year stepped catch rebuilding plan and 67% commercial allocation of TAC (an expected 25.5 percent initial harvest reduction). Rec: The initial annual recreational quota in whole weight for vermilion snapper will be 0.487 million pounds based on a 10-year stepped catch rebuilding plan and 33% recreational allocation of TAC (an expected 25.5 percent initial harvest reduction).

Alternative 6	Closed Seasons	Com: The commercial closed season for vermilion snapper will be August 1 through September 30 and December 1 through 31 (an expected 24.8 percent initial harvest reduction). Rec: The recreational closed season for vermilion snapper will be May 1 to June 21 (an expected 25.5 percent initial harvest reduction).

Method of Analysis

Fishery management is a type of social investment in which society invests in greater future fish abundance by restricting current harvest rates. Society invests in the short-term by incurring costs in the form of lower commercial harvests and higher harvesting costs per pound for commercial fishing, less domestically harvested fish available for retail consumption, lower recreational harvests and less enjoyment from recreational fishing, and higher monitoring and enforcement costs. If management is effective biologically, the abundance of fish will increase over time, which will allow society to benefit in the longer-term through larger commercial and recreational harvests, lower commercial harvesting costs per pound, and more domestically caught fish available for retail consumption.

The economic analysis of management alternatives is treated as an investment problem by evaluating the present value of short-term losses that would be incurred and longer-term gains that are expected to be realized over time as a result of management. In this analysis, the present value of quasi-producer surplus was calculated for the proposed management alternatives over a 10 year time horizon, from 2004-2013. The economic measure of performance was net operating incomes for boat owners, captains and crews, and excluded consideration of fixed costs. It is assumed that management alternatives will not influence retail fish prices because consumers can readily purchase alternative domestically landed or imported species.[4] The 10 year time period was chosen for analysis to match the number of years required to rebuild the vermilion snapper resource.

Logbook data for the three most recent years for which reasonably complete data are available, 2000-2002, were used to simulate the fishery with and without management. All trips that reported at least 1 pound of vermilion snapper were included in the analysis (Table 2). On average from 2000-2002, 441 boats made 3,745 trips that landed at least one pound of vermilion snapper, and landed 1.77 million pounds of vermilion snapper worth $3.27 million. Vermilion snapper was the primary revenue species on some trips and a secondary species on other trips (Fig. 2 and 3). On average for 2000-2002, trips with at least one pound of vermilion snapper landed a total of 7.30 million pounds of all species combined worth $13.81 million.

Table 2. Summary of logbook data for trips that landed at least one pound of vermilion snapper.

Trips with at least 1 pound of vermilion snapper	2000	2001	2002	Average
Boats	432	453	438	441
Trips	3,507	3,654	4,075	3,745
Pounds Verm Snap (millions)	1.500	1.747	2.071	1.773
Revenues Verm Snap (millions)	$2.838	$3.270	$3.705	$3.271

[4] By assumption, the supply of imported fish is completely elastic, which means that short-term reductions in commercial harvests of vermilion snapper can be offset by increases in imports without increasing retail consumer prices. In the longer-term, increases in the supply of domestic vermilion snapper will displace imports in retail markets without decreasing retail consumer prices.

Pounds all species (millions)	6.466	7.425	8.021	7.304
Revenues all species (millions)	$11.902	$14.255	$15.272	$13.810

During the simulation, each reported trip was subjected to the proposed rule to be examined, and the effects of the rule on trip catches, revenues and costs were calculated. The number of trips, pounds and revenues for vermilion snapper and all other species, trip costs and net operating revenues were totaled for all trips within each logbook year (2000-2002), and then averaged across all three years. This process was repeated for each of the 10 years analyzed for each management alternative, with each 3-year average from logbook data recorded as the expected outcome of the policy for that year in the planning horizon. The economic performance of the fishery under the status quo, *i.e.*, the situation without additional management, was evaluated in the same manner.

Total fishing-related mortality was calculated at the end of each simulated fishing year and used to calculate the biomass of vermilion snapper available for harvest at the beginning of the next year. Fishing-related mortality included commercial landings, deaths due to release mortality among commercially discarded vermilion snapper, and an estimate of harvest and release mortality in the recreational sector.

The biomass of vermilion snapper was updated according to the Pella-Tomlinson surplus production model with parameters that were estimated in the latest stock assessment by Porch and Cass-Calay (2001).

$$B_{t+1} = \frac{B_t(1 + PellaR\,\Delta t) - (Q_t^C + D_t^C + Q_t^R + D_t^R)\,\Delta t}{1 + PellaR\,\Delta t\left(\frac{B_t}{PellaK}\right)^{(PellaM-1)}}$$

Variable B_{t+1} refers to biomass at the beginning of year *t+1*, Q_t^C refers to the annual commercial harvest (in pounds) in year *t*, D_t^C refers to pounds discarded commercially in year *t*, Q_t^R refers to the annual recreational harvest (in pounds) in year *t*, and D_t^R refers to pounds discarded recreationally in year *t*. The parameter for intrinsic growth rate, *PellaR*, in the Pella-Tomlinson model was estimated as 0.63661 with a standard error of 0.42. The carrying capacity, *PellaK*, was estimated as 21,177 (in thousands of pounds, whole weight) with a standard error of 14,792. The exponent, *PellaM*, was set equal to 2.0 by assumption; hence, the estimate of maximum sustainable yield (MSY) was one-half the estimated carrying capacity. The estimate for biomass in year *t+1* was derived from a difference equation that was integrated over 16 discrete sub-intervals for each year. Hence, variable Δt=0.0625.

The updated estimate of biomass at the beginning of each year was used to update the quantities of vermilion snapper caught on each trip during the simulated fishing year.

$$h_{s,j,t} = \begin{cases} h_{s,j,0}\left(\frac{B_t}{B_0}\right) \le 1000 * daysaway_j & for\ s = vs \\ h_{s,j,0} & for\ s \ne vs \end{cases}$$

Variable $h_{s,j,t}$ refers to catch of species *s* on trip *j* in year *t*, and $h_{s,j,0}$ refers to catch on the same trip during the 2000-2002 base period. Catches of vermilion snapper per trip (*i.e.*, when $s = vs$) were assumed to change over time in proportion to the predicted change in biomass at the beginning of year *t*, B_t, compared to initial biomass, B_0. Therefore, $h_{vs,j,t}$ is less than $h_{vs,j,0}$ for management status quo when biomass is declining (*i.e.*, when $B_t < B_0$), and $h_{vs,j,t}$ is greater than $h_{vs,j\ 0}$ when management successfully enables biomass to increase (*i.e.*, when $B_t > B_0$). An arbitrary maximum catch of 1000 pounds per day fished was imposed so that simulated catches of vermilion snapper would not increase to exorbitantly high levels. The quantities of species other than vermilion snapper (*i.e.*, when $s \neq vs$) caught on each trip were not changed over time because the proposed management alternatives were assumed to change the abundance of vermilion snapper but not the abundance of other species.[5]

The economic performance of the commercial fishery was calculated as the present value, PV, of net operating revenues summed over all trips during the 10 year study period. A discount rate of r=7% was used. Net operating revenues for trip j in year t were calculated as trip revenues from all species, $TR_{j,t}$, minus routine trip costs, $TC_{j,t}$, which include fuel, oil, bait, ice, and other supplies, and exclude labor costs and fixed costs. Thus, net operating revenues are interpreted as the combined gross incomes to boat owners, captains and crew members. Fixed costs were not deducted because data are not available with which to determine the fraction of each boat's fixed costs that should be allocated to the vermilion snapper fishery and its other fishing activities.

$$PV = \sum_{t=1}^{t=10} \sum_{j=trips} (TR_{j,t} - TC_{j,t}) \ (1+r)^{-t}$$

The present value for each management alternative was compared to the present value for the status quo (*i.e.*, no additional management) to determine if the proposed alternatives are

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[5] A more complete ecosystem approach to modeling the biological system could predict that changes in the abundance of vermilion snapper might change catches of other species if their abundances are interrelated via a predator-prey relationship or through competition for limited habitat and/or food supply, but this type of model is beyond the scope of the present work.

expected to generate net benefits or losses to commercial fishermen over the 10 year study period. Net benefits are assumed to accrue to the fishery if PV with management exceeds PV given the status quo. A net loss would accrue if PV with management is less than PV given the status quo.

Method of Modeling Management Alternatives

The status quo was simulated by projecting catches, revenues and harvesting costs in the fishery without additional management, and was compared to the projected outcomes for each proposed management alternative to determine their economic effects. The proposed management alternatives included minimum size limits, trip limits, seasonal closures, and quotas (see Table 1) which were modeled by restricting the ability to catch or keep vermilion snapper based on logbook trip reports from 2000-2002.

Minimum size limits were modeled by assuming that an additional (when compared to the status quo) percentage, ρ^{C}_{msl}, of vermilion snapper on each trip are undersized and must be culled from the catch and discarded. If trip revenues exceeded trip costs after accounting for the additional undersized vermilion snapper, then losses were measured as the reduction in trip revenues from vermilion snapper. Undersized fish were assumed to have been caught, discarded and subject to release mortality.

Analysis of minimum size limits:

$$q_{vs,j,t} = h_{vs,j,t}\,(1 - \rho^{C}_{msl})$$
$$d_{vs,j,t} = h_{vs,j,t}\,\rho^{C}_{msl}$$
$$TR_{j,t} = p_{vs,t}\,q_{vs,j,t} + \sum_{s \neq vs} p_{s,t}\,h_{s,j,t}$$
$$TC_{j,t} = TC(\sum_{all\ s} h_{s,j,t})$$

Variable $q_{vs,j,t}$ denotes quantity of vermilion snapper kept on trip j in year t, and $d_{vs,j,t}$ is quantity discarded. The harvest of other species, $h_{s,j,t}$ for $s \neq vs$, is assumed not to be affected by the proposed minimum size limit for vermilion snapper. In the simulation model, trip costs, $TC_{j,t}$, are a function of total catch, including discards, and are not changed by the minimum size limit. Data were not available with which to estimate the potential additional costs of culling and discarding undersized fish. Trip revenues, $TR_{j,t}$, are based on quantities kept and price per pound, $p_{s,t}$. Hence, the loss in revenues due to a minimum size limit is determined as $p_{vs,t}\,(h_{vs,j,t} - q_{vs,j,t})$. However, if the trip becomes unprofitable with the minimum size limit, then losses were measured as a reduction in net operating revenues, which included the loss in revenues from all species minus the savings of trip costs not incurred the trip was recorded as not taken. Vermilion snapper were considered to have never been landed rather than landed, discarded, and subject to release mortality. In this event, $h_{vs,j,t} = q_{vs,j,t} = d_{vs,j,t} = TR_{j,t} = TC_{j,t} = 0$.

The percentages that define the additional undersized fish associated with each proposed minimum size limit were held constant throughout the 10-year study horizon. When effective biologically, minimum size limits gradually change the age and size distribution of the resource and the percentage of undersized fish landed. However, the biological model for vermilion snapper is not age-structured; hence, it is not possible to endogenously determine the additional undersized fish that would be landed each year.

Estimates for ρ^{C}_{msl} appear in the first row in Table 4.2.3.1.5 in the Public Hearing Draft for Amendment 23 (GMFMC 2004). The percentages associated with the row for 0% release mortality reflect the effect of the minimum size limit on the ability of fishermen to retain catches of vermilion snapper, which is the relevant concept for an economic analysis of the commercial fishery. Rows associated with non-zero levels of release mortality are used by biologists to calculate expected net reductions in overall fishing-related mortality, and include survival from the catch-and-release process. Hence, the expected net reduction in overall fishing-related mortality is less than the percentage reduction in fish that may be kept by fishermen.

These percentages refer to numbers of fish smaller than alternative minimum size limits. However, the simulation model works with quantities of vermilion snapper reported on logbook trips rather than numbers of fish. Hence, this method of simulating the effect of minimum size limits is an approximation for the preferred method that would use numbers of fish, but is not thought to introduce a significant error into the analysis because the average weight of each vermilion snapper landed is approximately 1 pound.

Some proposed management actions combine trip limits and minimum size limits. In this event, the simulation model reduces catches according to the percentage of undersized fish before determining if the trip limit would be restrictive. Undersized fish are considered to have been landed, discarded and subject to release mortality whenever the trip would remain profitable after accounting for the effects of the size and trip limits.

Trip limits were modeled as a maximum allowable catch per trip for vermilion snapper. Trips with catches less than the trip limit, after accounting for the effects of minimum size limits, do not incur additional losses due to the trip limit.

Trips with catches of vermilion snapper in excess of the trip limit, TL_{vs}, were treated in one of several ways. If trip revenues exceeded trip costs after restricting the catch of vermilion snapper to the trip limit and if vermilion snapper *was not* the primary source of revenue on the trip, then losses were measured as the reduction in the value of vermilion snapper landed. The quantity of vermilion snapper in excess of the trip limit is assumed to have been caught, discarded, and subject to release mortality because the trip would continue in search of its top-revenue producing species. Trip costs do not change.

Analysis of trip limits when $0 < TL_{vs} \leq h_{vs,j,t}\,(1 - \rho^{C}_{msl})$ *and vermilion snapper was not the top-revenue species on the trip (i.e., when* $p_{vs,t}\, q_{vs,j,t} \neq max[p_{vs,t}\, q_{vs,j,t},\ p_{2,t}\, h_{2,j,t},\ p_{3,t}\, h_{3,j,t},\ \ldots,\ p_{s,t}\, h_{s,j,t}]$*):*

$$
\begin{aligned}
q_{vs,j,t} &= TL_{vs} \\
d_{vs,j,t} &= h_{vs,j,t} - TL_{vs} \\
TR_{j,t} &= p_{vs,t}\, q_{vs,j,t} + \sum_{s \neq vs} p_{s,t}\, h_{s,j,t} \\
TC_{j,t} &= TC(h_{vs,j,t} + \sum_{s \neq vs} h_{s,j,t})
\end{aligned}
$$

If trip revenues exceeded trip costs after restricting the catch of vermilion snapper to the trip limit and if vermilion snapper *was* the primary source of revenue on the trip, then the trip was assumed to be cut short by the trip limit. The quantity of vermilion snapper in excess of the trip limit was assumed to have never been caught, and hence was not subject to release mortality. Catches of species other than vermilion snapper were reduced by the same percentage as vermilion snapper. Trip costs were assumed to decline because fewer pounds were landed.

Analysis of trip limits when $0 < TL_{vs} \leq h_{vs,j,t}$ $(1 - \rho^{C}_{msl})$ and vermilion snapper was the top-revenue species on the trip (i.e., when $p_{vs,t}\, q_{vs,j,t} = \max[p_{vs,t}\, q_{vs,j,t},\ p_{2,t}\, h_{2,j,t},\ p_{3,t}\, h_{3,j,t}, \ldots,\ p_{s,t}\, h_{s,j,t}]$):

$$
\begin{aligned}
q_{vs,j,t} &= TL_{vs} \\
h'_{vs,j,t} &= \frac{TL_{vs}}{(1-\rho^{C}_{msl})} \\
d_{vs,j,t} &= h'_{vs,j,t} - TL_{vs} = \rho^{C}_{msl}\, h'_{vs,j,t} \\
h'_{s,j,t} &= h_{s,j,t}\, \frac{h'_{vs,j,t}}{h_{vs,j,t}} \quad \textit{for } s \neq vs \\
TR_{j,t} &= p_{vs,t}\, q_{vs,j,t} + \sum_{s \neq vs} p_{s,t}\, h'_{s,j,t} \\
TC_{j,t} &= TC(h'_{vs} + \sum_{s \neq vs} h'_{s,j,t})
\end{aligned}
$$

If the trip limit would cause trip revenues to fall below trip costs, then the trip was recorded as not taken, and losses were measured as a reduction in net operating revenues, which included the loss in revenues from all species minus the savings of trip costs not incurred. Vermilion snapper were considered to have never been landed rather than landed and discarded. In this event, $h_{vs,j,t} = q_{vs,j,t} = d_{vs,j,t} = TR_{j,t} = TC_{j,t} = 0$. Because trip-level catches of vermilion snapper are increased over time in proportion to the projected growth in biomass, individual trips may be unaffected by the proposed trip limit early in the 10 year study period, but may be constrained by the trip limit during a later year in the analysis.

Trip limits create an incentive for fishermen to take shorter, but more frequent fishing trips. However, this model assumes that fishermen cannot take extra trips in response to the trip limit.

Seasonal closures were modeled by setting a trip limit equal to zero during the periods to be closed. Since logbook data record the month and day landed, trips that landed during the proposed dates for closure were subjected to the zero trip limit. In the multispecies reef fish fishery, vermilion snapper can be landed as primary or secondary species on a trip. If trip revenues exceeded trip costs without vermilion snapper (because of the zero trip limit), then losses were measured as the reduction in the value of vermilion snapper, and reported landings of vermilion snapper were assumed to have been caught, discarded, and subject to release mortality.

Analysis of a no-harvest rule, $TL_{vs} = 0$:

$$
\begin{aligned}
q_{vs,j,t} &= 0 \\
d_{vs,j,t} &= h_{vs,j,t} \\
TR_{j,t} &= \sum_{s \neq vs} p_{s,t}\, h_{s,j,t} \\
TC_{j,t} &= TC(h_{vs,j,t} + \sum_{s \neq vs} h_{s,j,t})
\end{aligned}
$$

If the trip became unprofitable with a zero trip limit, then the trip was recorded as not taken, and vermilion snapper were considered to have never been landed rather than landed and discarded. In this event, $h_{vs,j,t} = q_{vs,j,t} = d_{vs,j,t} = TR_{j,t} = TC_{j,t} = 0$.

Seasonal closures create an incentive for boats to re-schedule trips to minimize the likely effect of the closure. However, this model does not accommodate this type of behavioral adaptation to regulation.

Fishery-wide quotas were modeled by setting a trip limit equal to zero after the quota is reached. Trips are unrestricted until the quota is reached. Then, the trip limit is set to zero and trips are evaluated in the same way as a seasonal closure. Trips that remain profitable with a zero trip limit are assumed to land and discard vermilion snapper. If the trip becomes unprofitable with a zero trip limit, then the trip was recorded as not taken, and vermilion snapper were considered to have never been landed rather than landed and discarded.

The total annual commercial harvest of vermilion snapper, Q_t^C, and total annual commercial discard mortality, D_t^C, feed back into the Pella-Tomlinson surplus production model to calculate the biomass of vermilion snapper at the beginning of the next year. The total commercial harvest was defined as the sum of harvest per trip, and total commercial discard was defined as the sum of discards per trip multiplied by the commercial discard mortality rate, γ^C.

$$Q_t^C = \sum_{j=trips} q_{vs,j,t}$$

$$D_t^C = \gamma^C \sum_{j=trips} d_{vs,j,t}$$

Also, annual estimates of recreational fishing mortality are needed to update population biomass with the Pella-Tomlinson surplus production model. The potential recreational harvest in year t was calculated by updating the average annual recreational harvest of vermilion snapper from 1998-2002 (0.536 million pounds, whole weight) in proportion to predicted changes in biomass.

$$H_t^R = H_0^R \left(\frac{B_t}{B_0} \right)$$

Variable H_t^R refers to total annual recreational catch of vermilion snapper in year t, H_0^R refers to the average annual recreational harvest during the 1998-2002 base period, B_t refers to biomass in year t, and B_0 refers to average initial biomass. For quota management, recreational mortality in terms of landings, Q_t^R, plus discard mortality, D_t^R, were modeled as the recreational quota, $quota^R$, plus the recreational discard mortality rate, γ^R, multiplied by the difference between potential harvest and the quota. If the potential harvest was less than the quota, then recreational mortality was equal to potential harvest, and there was no discard or discard mortality.

Recreational mortality with quota management:

$$\left.\begin{array}{l} Q_t^R = quota^R \\ D_t^R = \gamma^R (H_t^R - quota^R) \end{array}\right\} \qquad for\ H_t^R > quota^R$$

$$\left.\begin{array}{l} Q_t^R = H_t^R \\ D_t^R = 0 \end{array}\right\} \qquad for\ H_t^R \leq quota^R$$

For all alternatives except quota management, recreational mortality was modeled by reducing potential harvest by the expected percentage reduction in recreational harvest due to management, ρ_k^R, plus recreational discard mortality defined as a proportion of the reduction in harvest due to management. Parameter ρ_k^R is assumed constant over time and equal to the expected percentage initial harvest reduction for each management alternative *k* as described in Table 1.

Recreational mortality with management other than quotas:

$$\begin{array}{l} Q_t^R = H_t^R (1 - \rho_k^R) \\ D_t^R = \gamma^R H_t^R \rho_k^R \end{array}$$

Thirty-three percent, $\gamma^C = 0.33$, of commercially discarded vermilion snapper and twenty percent, $\gamma^R = 0.20$, of recreationally discarded vermilion snapper were assumed to die, and hence were not available to help rebuild the resource. Estimates of release mortality rates were obtained from the Public Hearing Draft for Amendment 23 (GMFMC 2004).

Method of Calculating Trip Revenues and Trip Costs

As already noted, logbook data do not include information about trip revenues. Therefore, average monthly prices were calculated from the NMFS Accumulated Landings System and merged with logbook trip reports by year, month, species and state. Trip revenues for each species were calculated as the product of average monthly prices and reported pounds per trip.

Information about trip costs were obtained from the 1993 economic survey of commercial reef fish boats in the Gulf of Mexico (Waters 1996). Trip costs were inflated from 1993 price levels to average 2000-2002 prices according to the producer price index for #2 diesel fuel.[6] The PPI for #2 diesel was fuel was 60.5 in 1993 and averaged 84.9 from 2000-2002. Hence, reported trip costs were increased by a factor of 84.9/60.5 = 1.40. The 2000-2002 base period was chosen so that costs match the same time period as logbook data that were used in the analysis.

Trip costs in the 1993 economic survey were identified by gear and type of fishing. For purposes of the current analysis, trip costs were examined for high-volume trips with vertical lines for red or vermilion snapper in the northern Gulf, low-volume trips with vertical lines for red or vermilion snapper in the northern Gulf, low-volume trips with vertical lines in the eastern Gulf, trips with bottom longlines, and trips with fish traps (Waters 1996). For each type of trip, trip costs, after adjusting to average 2000-2002 price levels, were regressed on pounds landed, days per trip away from port, and crew size (Table 3). The independent variables were chosen to match the type of information available in logbook data for each trip. A more rigorous analysis that includes additional characteristics of each boat is reserved for future research.

[6] Data for the Producer Price Index for #2 diesel fuel (series WPU057303) were obtained from the U.S. Department of Labor, Bureau of Labor Statistics website www.bls.gov.

Table 3. Estimated parameters (with standard errors in parentheses) for cost per trip by reef fish boats in the Gulf of Mexico. Dependent variable was reported expected cost per trip updated to average 2000-2002 price levels according to the PPI for #2 diesel fuel.

Parameter	High-Volume Trips with Vertical Lines for Red or Vermilion Snappers	Low-Volume Trips with Vertical Lines for Red or Vermilion Snappers	Low-Volume Trips with Vertical Lines for Reef Fish in the Eastern Gulf	Trips with Bottom Longlines	Trips with Fish Traps/Pots
Intercept	1052.77 (203.79)	-213.05 (127.93)	137.11 (63.60)	-654.01 (495.35)	149.39 (72.24)
Days per trip	-233.92 (82.52)	180.83 (61.02)	57.44 (20.52)	142.74 (31.74)	73.97 (24.22)
Days per trip squared	40.89 (7.01)	-8.10 (4.60)	n.a.	n.a.	n.a.
Persons aboard	n.a.	70.35 (38.84)	n.a.	401.28 (145.74)	n.a.
Thousands of pounds landed, all species	129.25 (54.10)	337.08 (89.88)	69.14 (29.09)	134.54 (50.25)	232.73 (53.40)
Number of observations	68	45	31	60	51
R-squared	0.71	0.83	0.45	0.60	0.63

The estimated coefficients from the trip cost equations were used to calculate expected trip costs for each trip in the logbook database for 2000-2002. Each reported trip in the logbook database was classified by primary gear, with primary gear defined as the top revenue producing gear for that trip. High-volume trips with vertical lines in the logbook database were defined as trips that landed 1500 pounds or more, regardless of species, and were matched with the cost equation in Table 3 for high-volume trips with vertical lines for red or vermilion snapper. Medium-volume trips with vertical lines in the logbook database were defined as trips that landed between 500 and 1499 pounds, and were matched with the cost equation in Table 3 for low-volume trips with vertical lines for red or vermilion snapper. Trips with bottom longlines and fish traps in the logbook database were matched with the corresponding cost equations in Table 3. All other logbook trips were assigned costs according to the cost equation in Table 3 for low-volume trips with vertical lines in the eastern Gulf.

The number of crew and days absent from port for each trip were assumed to remain unchanged over time. However, pounds landed per trip changes over time as the vermilion snapper biomass changes. Each trip retained the same cost equation for the entire time horizon, even if total pounds landed for that trip were to increase from the low-volume to medium-volume category, or medium-volume to high-volume category. It is presumed that basic cost structure is determined by the boat and its configuration, which are assumed constant over time.

Other Methodological Issues

The NMFS forecasted the biomass of vermilion snapper based on the Pella-Tomlinson surplus production model, and found that biomass was expected to decline. However, the stock assessment was based on data from 1986-1999, whereas more recently available data suggest that the condition of the vermilion snapper stock may have improved. An unresolved question is whether recent improvements reflect a temporary upswing along a long-run declining trend in biomass, or a permanent reversal of the predicted long-run decline. Without an updated stock assessment to resolve the issue, amendment 23 and this analysis presume that recent improvements are temporary, and that stock biomass without additional management will decline according to the predictions of the Pella-Tomlinson model, but that the decline will start from a higher level of catch than originally estimated by the stock assessment.

Amendment 23 increases the predictions of total allowable catches in each rebuilding plan to accommodate recent improvements in stock condition that occurred since the completion of the stock assessment. The adjustment factor was determined as the new, higher TAC considered by the NMFS to be consistent with rebuilding the stock to desired biological levels divided by the corresponding TAC from the previous, unadjusted rebuilding plan. The resulting adjustment factor was 1.21656. Hence, total allowable landings from the original rebuilding plan were multiplied by 1.21656 to account for recent improvements in stock condition and better match the higher, recently observed catches. However, proper use of the estimated Pella-Tomlinson surplus production model requires landings to be expressed in original units. Therefore, landings and discard mortality from the analysis were rescaled to original units by dividing by 1.21656 before updating the biomass of vermilion snapper at the beginning of the next simulated year.

The starting year for analysis is 2004. Due to the predicted declining trend in stock biomass, the expected harvest for 2004 should be less than the average harvests for 2000-2002 by approximately 20%. Therefore, the reported catches of vermilion snapper on each logbook trip, $h_{vs,j,0}$, (which pertain to the 2000-2002 period) were reduced by 20% to acknowledge the reductions in biomass and harvests that were predicted to have occurred between the 2000-2002 period and 2004, and to match logbook catches with predicted catches from the biological analysis of the status quo fishery. Similarly, average annual recreational harvests for the base period, H_0^R, were reduced by 20% to account for reductions in biomass that were predicted to have occurred between the base period and 2004.

Most commercial catches of vermilion snapper were landed and reported in logbooks as gutted weights and, for purposes of this analysis, converted to an equivalent whole weight basis by multiplying by 1.11. Logbook data were current as of September 25, 2003.

Model Results

Status Quo:

The vermilion snapper resource is expected to decline gradually if additional management is not implemented. Biological analyses conducted in support of Amendment 23 estimated the biomass of vermilion snapper at the beginning of 2004 to be approximately 2.5 million pounds, and that it would decline to approximately 1.5 million pounds by the end of 2013 (Fig. 4). Commercial landings are expected to decline from 1.5 million pounds in 2004 to approximately 0.9 million pounds in 2013 (Fig. 5).

The bioeconomic model is slightly more optimistic with regards to both biomass and landings, primarily because fishing effort would decline over time in response to a declining vermilion snapper population, whereas the biological analysis in Amendment 23 assumed that the fishing mortality rate would remain constant over time. As vermilion snapper become less abundant, catch rates per trip and the profitability of harvesting vermilion snapper would decline. Hence, fishing effort would be expected to decline also, which results in a slightly smaller aggregate harvest of vermilion snapper initially which, in turn, depletes the population biomass at a slightly lower rate. Over time, the net result is a slightly larger biomass than predicted by the biological analysis in Amendment 23 (Fig. 4), and a marginally higher aggregate harvest after 5 years (Fig. 5).

Without additional management between 2004 and 2013, commercial fishermen are expected to land 11.6 million pounds of vermilion snapper worth $21.5 million. Also, fishermen are predicted to land approximately 55.9 million pounds of other species worth $106.8 million on these same trips. After deducting routine trip costs, boat owners, captains and crew members are expected to earn approximately $90.9 million over the 10 year study period to pay for labor and fixed costs. Present value would be $68.6 million when evaluated with a 7% discount rate.

Alternative 2:

Management alternative 2 proposed a commercial trip limit of 1625 pounds, whole weight, for vermilion snapper (Table 1). Logbook data for 2000-2002 indicate that 947 of 2667 trips (35.5%) landed more than 1600 pounds of vermilion snapper when it was the top revenue species on the trip (Fig. 6). However, most trips caught vermilion snapper as a secondary source of revenue, and as expected, relatively few of them (67 of 8569, or less than 1%) landed more than 1600 pounds of vermilion snapper (Fig. 6). Initially, the simulation model predicted even fewer trips with catches in excess of the proposed trip limit because logbook catches were reduced by 20% to account for the predicted decline in biomass between the 2000-2002 base period and the first year of analysis in 2004. The simulated number of trips with catches in excess of the trip limit increased over time as biomass increased in response to regulation.

Commercial fishermen are expected to land 14.6 million pounds of vermilion snapper worth $27.1 million during the 10-year rebuilding period, and earn a present value of $69.8

million in net operating revenues. Initially, the simulation model predicted that a 1625 pound trip limit would reduce commercial landings and net operating revenues to boat owners, captains and crew members when compared to predictions without additional management (*i.e.*, the status quo). Landings would decline for the first 2 years of management, would be about the same after 3 years, and then would be greater than the status quo in years 4-10 (Fig. 7). The present value of net operating revenues would decline for the first 3 years of management and then would be greater than the status quo in years 5-10 (Fig. 8). However, it would require 8 years for the accumulated long-term gains in present value to completely offset the initial 3 years of losses.

There were relatively few discards associated with the 1625 trip limit (Fig. 7). By assumption, simulated trips were terminated after reaching the trip limit when vermilion snapper was the top revenue species for the trip, and few trips were restricted by the trip limit when vermilion snapper was not the top revenue species. Vermilion snapper that were not landed due to the trip limit contributed to a larger spawning stock biomass. The biomass of vermilion snapper was predicted to increase to approximately 9.2 million pounds by the end of the 10-year rebuilding period in 2013. Hence, biomass would be rebuilt to a level greater than the minimum spawning stock threshold (MSST) of 7.9 million pounds.

Alternative 3:

Management alternative 3 proposed implementation of a 12 inch minimum size limit (Table 1). Based on data presented by Chih (2003), table 4.2.3.1.5 in the Public Hearing Draft (GMFMC 2004) calculated that an additional 42.8% of vermilion snapper harvested by the commercial sector would be undersized and must be released rather than kept.

The simulation model predicted that commercial fishermen and the vermilion snapper population would be worse off with a 12 inch minimum size limit than with a 1625 pound trip limit. Commercial fishermen are expected to land 12.6 million pounds of vermilion snapper during the 10-year rebuilding period, and earn a present value of $67.8 million in net operating revenues. When compared to the status quo, landings are predicted to decline for the first 4 years of management, and then would be greater than the status quo in years 5-10 (Fig. 9). It would require 9 years before the accumulated long-term change in landings would be positive. The present value of net operating revenues would decline for the first 5 years of management and then would be greater than the status quo in years 6-10 (Fig. 10). However, the expected gains in present value during years 6-10 would not be sufficient to offset losses incurred during years 1-5. As a result, commercial fishermen would incur an accumulated net loss in the present value of their incomes of approximately $0.9 million over the 10-year rebuilding period.

The simulation analysis predicts that commercial discards would be substantially greater with a 12 inch minimum size limit than with any of the other proposed alternatives. By assumption, an additional 42.8% of the catch from every trip would be undersized and discarded, unless the trip were to become unprofitable, in which case fish would not be caught. Moreover, commercial discards are predicted to increase over time. As the population of vermilion snapper increases, commercial catches, and hence discards, per trip are expected to increase also. The population of vermilion snapper is predicted to increase to approximately 7.7 million pounds by the end of the 10-year rebuilding period in 2013. Hence, biomass would be rebuilt to approximately 3 times its current level, but still would be less than the minimum spawning stock threshold of 7.9 million pounds.

Alternative 4:

Management alternatives 4A and 4B proposed a combination of commercial trip limits and an 11 inch minimum size limit (Table 1). Overall, the two alternatives are not expected to differ greatly. Alternative 4A places a little less of the burden of stock recovery on the commercial sector by specifying a 2300 pound trip limit for the commercial sector and a 7 fish bag limit for the recreational sector. Conversely, alternative 4B places a little more of the burden of stock recovery on the commercial sector by specifying a 2250 pound trip limit for the commercial sector and a 10 fish bag limit for the recreational sector.

Logbook data for 2000-2002 indicate that 636 of 2667 trips (23.8%) landed more than 2200 pounds of vermilion snapper when it was the top revenue species on the trip, and that relatively few trips (20 of 8569, or less than 1%) landed more than 2200 pounds of vermilion snapper when it was not the top revenue species (Fig. 6). Recall that, initially, the simulation model predicted even fewer trips with catches in excess of the proposed trip limits because logbook catches were reduced by 20% to account for the predicted decline in biomass between the 2000-2002 base period and the first year of analysis in 2004. In addition, the simulation model reduces catches according to the percentage of undersized fish before determining if the trip limit would be restrictive. Based on data presented by Chih (2003), table 4.2.3.1.5 in the Public Hearing Draft (GMFMC 2004) calculated that an additional 21.9% of vermilion snapper harvested by the commercial sector would be undersized and must be released rather than kept with an 11 inch minimum size limit.

The simulation model predicted that, when compared to the status quo, both alternatives would generate fewer pounds landed of vermilion snapper during the first 3 years of the rebuilding period, with an overall net gain in cumulative landings occurring during the 7th year of recovery (Fig. 11 and 12). Over the 10 year rebuilding period, commercial fishermen were predicted to harvest approximately 14.0 million pounds of vermilion snapper with alternative 4A and 13.8 million pounds with alternative 4B. With its higher commercial trip limit, alternative 4A would allow slightly more trips, pounds of vermilion snapper landed, and revenues net of harvesting costs than alternative 4B. Hence, the present value of net operating revenues generated over the 10 year study period was marginally greater than with 4B. The present value of net operating revenues for both alternatives was less than the status quo during the first 4 years of the rebuilding period, with an overall gain in cumulative present value occurring during the 9th year of recovery (Fig. 13 and 14). However, the predicted gains in landings are large in years 8-10, so that the cumulative gains in present value after 10 years are approximately $1.0 million for alternative 4A and $0.7 million for alternative 4B.

Both alternatives, with their 11 inch minimum size limits and 2250-2300 pound trip limits, generated more favorable economic outcomes over 10 years than alternative 3 with its 12 inch minimum size limit and no trip limit, but less favorable outcomes than alternative 2 with its 10 inch minimum size limit and 1625 pound trip limit. Therefore, commercial fishermen probably would prefer trip limits rather than minimum size limits, which appear to maximize economic losses to commercial fishermen.[7]

The simulation analysis predicted that the population of vermilion snapper would increase to approximately 7.4 million pounds with alternative 4A by the end of the 10-year rebuilding

[7] The reader is reminded that the biological model used here is not age-structured, and that the currently observed percentages of fish smaller than proposed minimum size limits are assumed to remain constant over time.

period in 2013, and 7.1 million pounds with alternative 4B. Hence, biomass would be rebuilt to nearly 3 times its current level, but would be less than the minimum spawning stock threshold of 7.9 million pounds.

Alternative 5:

Management alternative 5 proposed annual quotas, with seasons to be closed when the quotas are filled (Table 1). Annual quotas would be determined from a 10-year stepped catch rebuilding plan in which annual allowable catches are set at 0.989 million pounds, whole weight, at the beginning of the rebuilding period and then increased to 1.378 million pounds at the beginning of year 5 and increased again to 1.769 million pounds at the beginning of year 8 in concert with the expected growth in biomass over time. Catches of vermilion snapper that occur after the quotas are filled must be returned to the water and are subject to release mortality.

Logbook data indicate that, on average for 2000-2002, commercial fishermen landed approximately 1.047 million pounds, whole weight, of vermilion snapper by the end of July (Fig. 15). Therefore, the proposed 0.989 million pound quotas would prohibit commercial landings of vermilion snapper from August through December. The simulation model predicted that commercial landings and net operating revenues would be less than the status quo during the first 4 years of the rebuilding period (Fig. 16 and 17). Quotas are increased in years 5 and 8, and predicted landings and net operating revenues exceed the status quo during years 5-10. By year 8, the cumulative gains in both landings and net operating revenues are expected to exceed the first 4 years of losses. The quotas would remain restrictive throughout the rebuilding period due to growth in biomass over time, which increases catch per trip and total landings.

The simulation analysis predicted that the population of vermilion snapper would increase to approximately 7.4 million pounds with alternative 5 by the end of the 10-year rebuilding period in 2013. Hence, biomass would be rebuilt to nearly 3 times its current level, but would be less than the minimum spawning stock threshold of 7.9 million pounds.

Alternative 6:

Management alternative 6 proposed a closure during the months of August, September and December for the commercial fishery (Table 1). Therefore, the effects of alternative 6 are expected to be less severe than for alternative 5 with its more extended August through December closure. In fact, commercial landings of vermilion snapper are predicted to total approximately 15.0 million pounds during the 10-year rebuilding period, which is the largest quantity from among all management alternatives. Also, the $72.0 million present value of net operating revenues was predicted to exceed the outcomes of the other alternatives. The simulation model predicted that commercial landings and net operating revenues would be less than the status quo during the first 3 years of the rebuilding period, and that by year 6, the cumulative gains in both landings and net operating revenues are expected to exceed the first 3 years of losses (Fig. 18 and 19).

The good economic outcomes occurred because catches per trip were modeled to increase over time in proportion to predicted increases in biomass. One result was that alternative 6 predicted the fewest discards from among the management alternatives because catches were unconstrained except during the closed months. Another result was that vermilion snapper that contributed to larger commercial landings were not available for stock recovery. Hence, alternative 6 predicted the least effective biological recovery. The simulation analysis predicted that the population of vermilion snapper would increase to approximately 6.3 million pounds by the end of the 10-year rebuilding period in 2013, which is 2.5 times its estimated current size, but less than the minimum spawning stock threshold of 7.9 million pounds.

Summary

Management alternatives have been proposed for the commercial vermilion snapper fishery, including trip limits, minimum size limits, quotas and seasonal closures. The predicted overall economic performance of all but one management alternative exceeded the predicted performance without additional management. Alternative 6 was predicted to yield a 4.9% increase in the present value of net operating revenues over the 10 year rebuilding period (Fig. 20). Alternatives 2, 4A, 4B and 5 were predicted to yield overall gains in present value between 1.1% and 2.3%. Alternative 3 was predicted to reduce present value by approximately 1.3%.

Each management alternative would reduce the profitability of fishing at current levels of biomass by restricting the ability of fishermen to catch or keep vermilion snapper. Some trips would remain profitable despite lower net operating revenues. Other trips would become unprofitable and would not be taken. All of the proposed alternatives are predicted to reduce the number of trips when first implemented. Alternatives 2, 4A and 4B are predicted to have the least effect on fishing effort because many trips would be unaffected by trip limits of 1625 pounds, 2300 pounds, or 2250 pounds (Fig. 21). Alternatives 5 and 6, which specify closures, would cause the largest reductions in fishing effort because all trips that landed during the closed periods would be affected.

Fishing effort with all alternatives except quotas are predicted to increase over time in concert with predicted increases in biomass (Fig. 21). Larger biomass yields greater pounds and revenues per trip, which would make a greater number of trips profitable, and for alternatives 2, 3, 4A and 4B would exceed trips under the status quo within approximately 5 years. The number of trips with quotas defined by a 10-year stepped catch rebuilding plan would exhibit a sawtooth pattern over time. Within each interval with constant quotas, growth in biomass would increase catch per trip, which would increase the rate at which the quota is filled each year. Therefore, the number of trips required to reach the quota would decline until the next increase in the quota. The simulation model predicted that the number of trips would decline gradually over time under the status quo.

The predicted trends over time for commercial landings of vermilion snapper (Fig. 22) and revenues net of operating costs (Fig.23) are similar to the trend in number of trips. All alternatives would entail initial reductions in landings and net operating revenues followed by increases over time as the biomass of vermilion snapper increases. When compared to the status quo, alternative 6 would provide the greatest accumulated gain in pounds of vermilion snapper landed and net operating revenues, and alternative 3 would yield the smallest gains.

Although net operating revenues are predicted to increase over time, the present values of net operating revenues are predicted to decline (Fig. 24). Present value is defined as a weighted sum of annual benefits, with benefits in the distant future receiving less weight than benefits received in the near future to account for the economic reality that \$1 received today is worth more than \$1 received 5 years in the future, for example.

The proposed alternatives would increase the volume of discards, especially since vermilion snapper is not the top-revenue species on many trips (Fig. 25). If vermilion snapper is not the top-revenue species, then fishermen are more likely to continue fishing and discard their catches of vermilion snapper than they are to stop catching vermilion snapper in response to management. Alternative 2 would generate the fewest discards because vermilion snapper was the top-revenue species on many trips with catches in excess of 1625 pounds. In this event, fishermen were assumed to terminate their trips upon reaching the trip limit, and the quantity of vermilion snapper in excess of the trip limit was assumed to have never been caught rather than being caught and discarded. On the other hand, the simulation model predicted that the 12 inch minimum size limit for alternative 3 would generate the greatest volume of discards because an additional 42% of vermilion snapper would be undersized, culled from the catch and discarded if the trip were to remain profitable. By assumption, 33% of discarded vermilion snapper would die and not contribute to future growth in biomass.

All alternatives were predicted to significantly increase the biomass of vermilion snapper, according to the deterministic surplus production model used in the analysis (Fig. 26). The status quo with no additional management was predicted to result in a gradual decline in biomass over time, whereas the proposed management alternatives were predicted to increase biomass by a factor of approximately 2.5 or more (*i.e.*, by 250% or more). The closed seasons associated with alternative 6 would be the least effective biologically, and the 1625 pound trip limit associated with alternative 2 would be the most effective. Only alternative 2 was predicted to yield a biomass that exceeds the minimum spawning stock threshold (MSST), defined as 75% of biomass that would support MSY, within 10 years. Alternatives 3, 4A, 4B and 5 were predicted to generate a biomass that was slightly less than MSST. Only alternative 6 yielded a biomass that was not within 10% of MSST by the end of the 10 year rebuilding period.

The use of logbook data to simulate the effects of proposed management actions is most appropriate in the short-term because logbooks report actual fishing behavior during a recent period of time. These data reflect the full range of harvesting activities and outcomes for trips that encounter vermilion snapper, from targeted to incidental capture of vermilion snapper, and included differences in species composition and fishing activities by area, gear, duration of trip, crew size, good luck and bad luck, and so forth. In this sense, this analysis is more realistic than conventional bioeconomic models, which specify a few discrete fishing classes defined by vessel size, gear type, area fished, or scale of operation, and with homogeneous fishing activity within each class.

Dockside prices, fuel and other input costs, the abundance of fish, regulation and other factors may change over time, and all interact to determine the profitability of fishing for vermilion snapper. Regulation tends to reduce the profitability of fishing, at least initially, and fishing effort for vermilion snapper may decline if some trips switch to other species. This analysis accounts for behavioral response by eliminating the currently observed trips that likely would become unprofitable given the proposed restrictions on the harvest and retention of vermilion snapper.

The use of logbook data becomes less reliable for longer-term analyses because they reflect catch rates and fishing behavior under current economic, regulatory and environmental conditions. Over time without additional management, persistent declines in the abundance of vermilion snapper may convince some boat owners to either fish less often or not at all for vermilion snapper. Conversely, additional boats may enter the vermilion snapper fishery over time if proposed regulations are successful in increasing the long-term abundance of vermilion snapper. This analysis does not account for potential changes in fleet size over time, and additional econometric analysis is needed to model this type of behavioral response to regulation.

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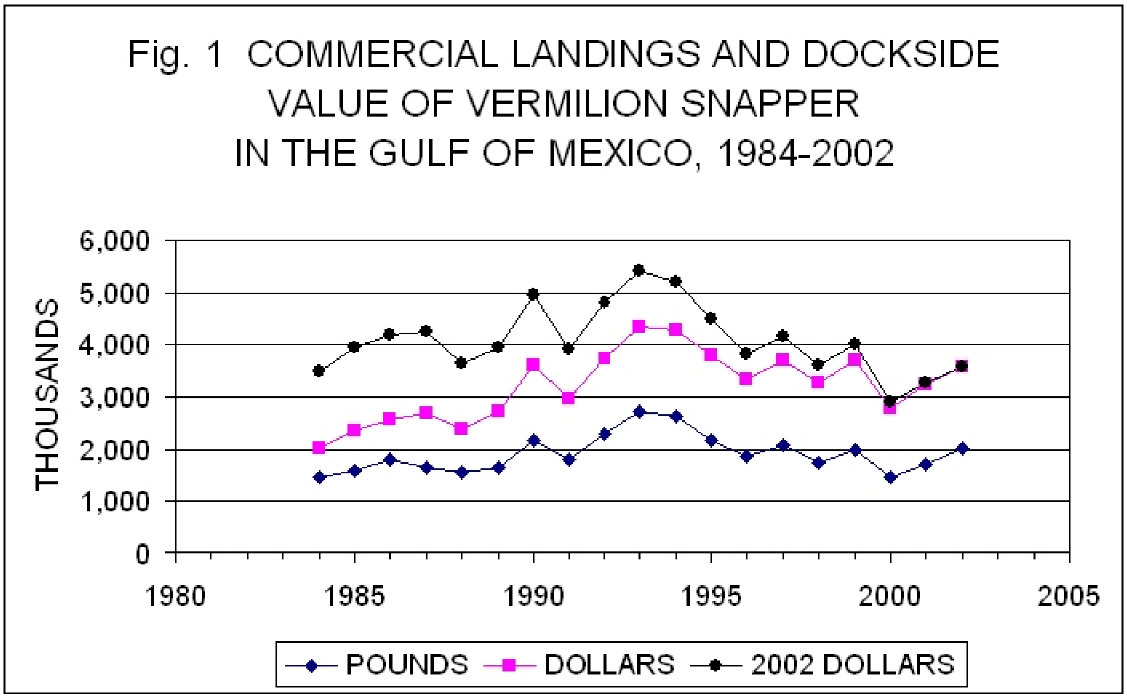


Fig. 1 COMMERCIAL LANDINGS AND DOCKSIDE VALUE OF VERMILION SNAPPER IN THE GULF OF MEXICO, 1984-2002
THOUSANDS
6,000
5,000
4,000
3,000
2,000
1,000
0
1980
1985
1990
1995
2000
2005
POUNDS
DOLLARS
2002 DOLLARS

Fig. 2. NUMBER OF TRIPS THAT LANDED VERMILION SNAPPER, BY TOP-REVENUE SPECIES ON EACH TRIP

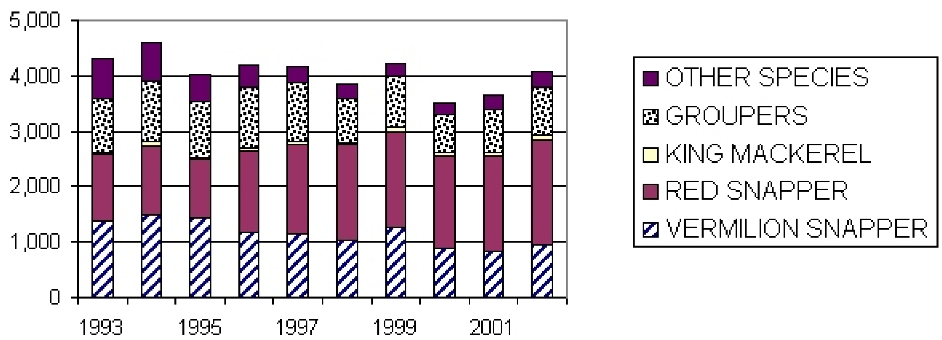
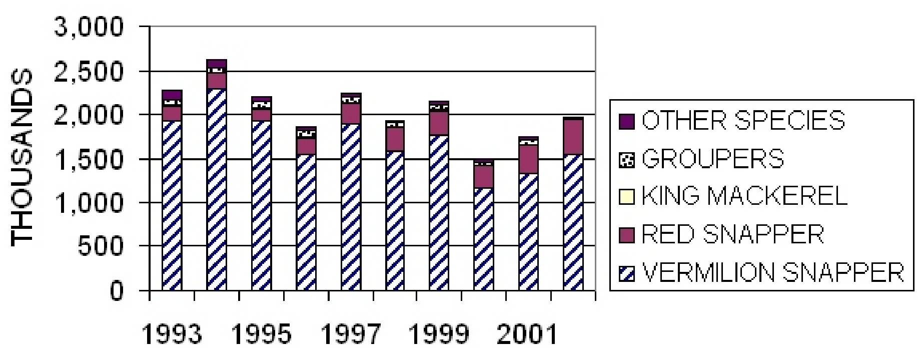


Fig. 3. POUNDS OF VERMILION SNAPPER LANDED, BY TOP-REVENUE SPECIES FOR EACH TRIP



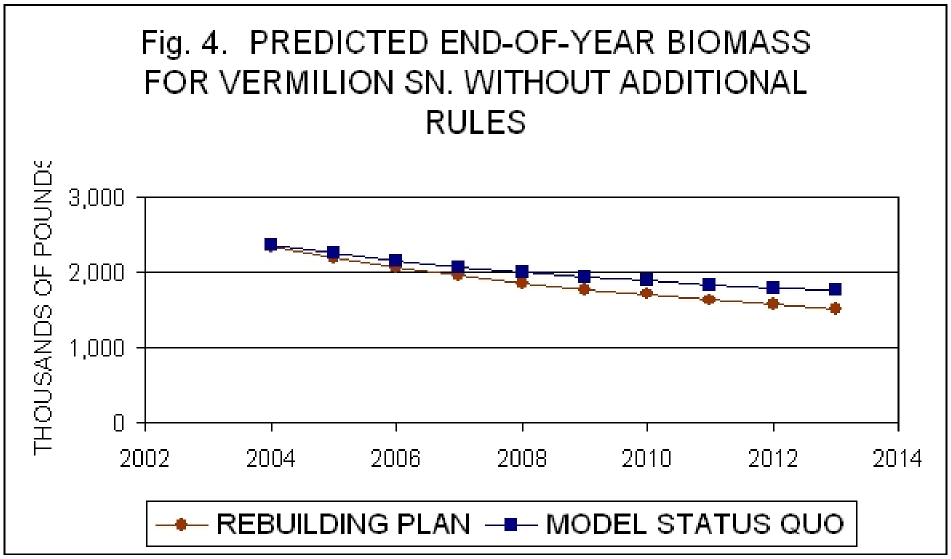


Fig. 4. PREDICTED END-OF-YEAR BIOMASS FOR VERMILION SN. WITHOUT ADDITIONAL RULES
THOUSANDS OF POUNDS
3,000
2,000
1,000
0
2002
2004
2006
2008
2010
2012
2014
REBUILDING PLAN
MODEL STATUS QUO

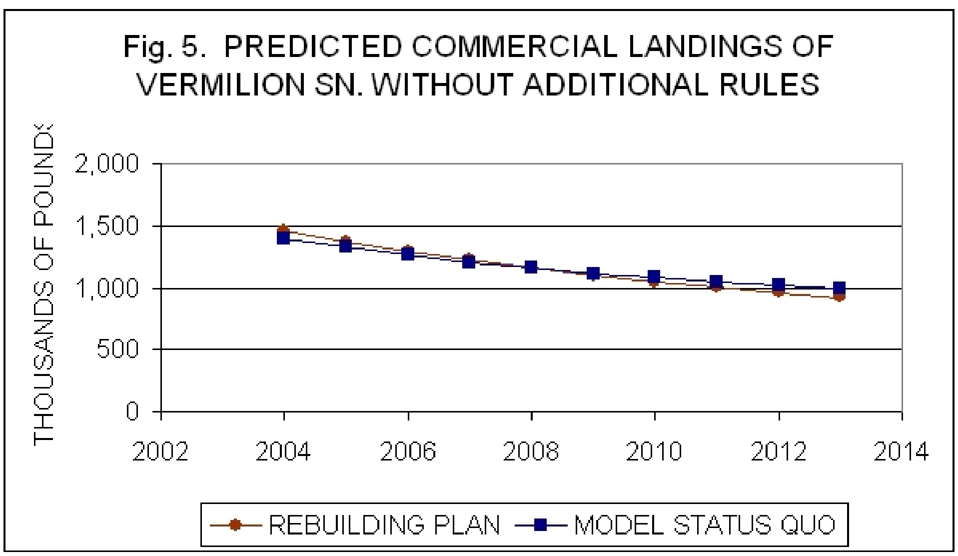


Fig. 5. PREDICTED COMMERCIAL LANDINGS OF VERMILION SN. WITHOUT ADDITIONAL RULES
THOUSANDS OF POUNDS
2,000
1,500
1,000
500
0
2002
2004
2006
2008
2010
2012
2014
REBUILDING PLAN
MODEL STATUS QUO

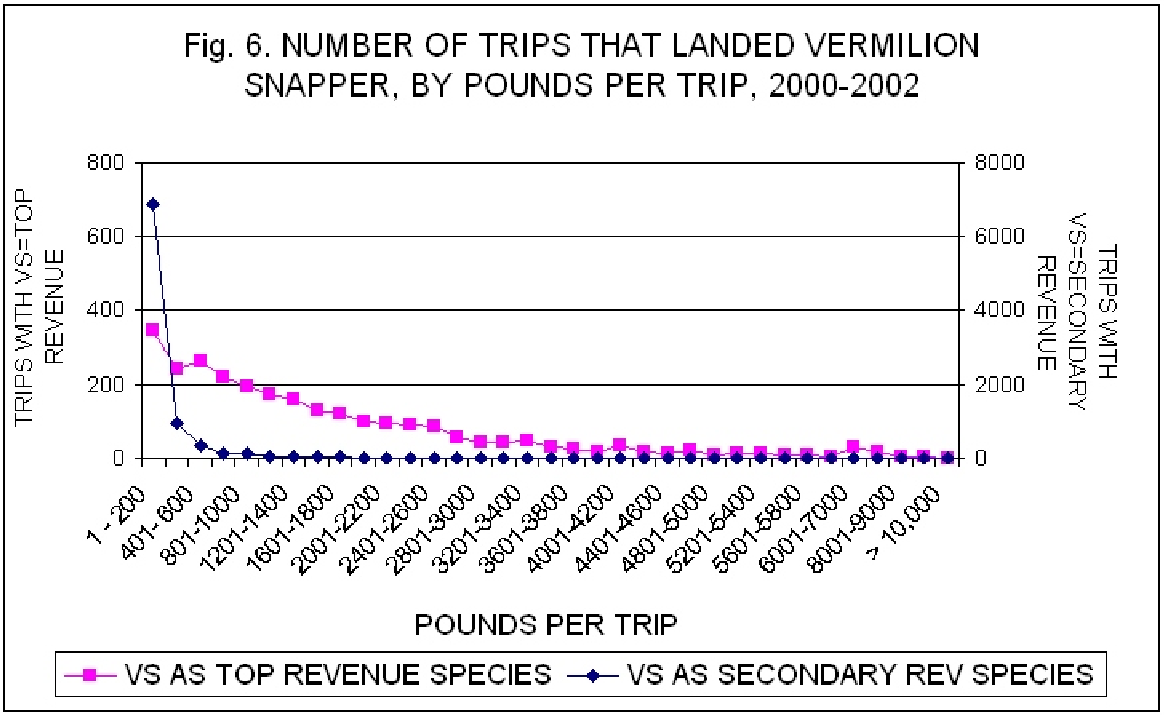


Fig. 6. NUMBER OF TRIPS THAT LANDED VERMILION SNAPPER, BY POUNDS PER TRIP, 2000-2002
TRIPS WITH VS=TOP REVENUE
TRIPS WITH VS=SECONDARY REVENUE
800
600
400
200
0
8000
6000
4000
2000
0
1 - 200
401-600
801-1000
1201-1400
1601-1800
2001-2200
2401-2600
2801-3000
3201-3400
3601-3800
4001-4200
4401-4600
4801-5000
5201-5400
5601-5800
6001-7000
8001-9000
> 10,000
POUNDS PER TRIP
VS AS TOP REVENUE SPECIES
VS AS SECONDARY REV SPECIES

Fig. 7. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN COMMERCIAL LANDINGS OF VERMILION SNAPPER WITH A 1625 POUND TRIP LIMIT

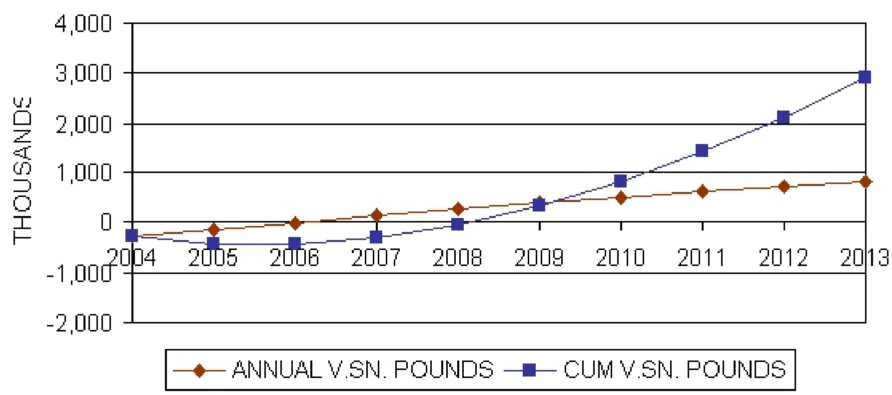


Fig. 8. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN PRESENT VALUE WITH A 1625 POUND TRIP LIMIT

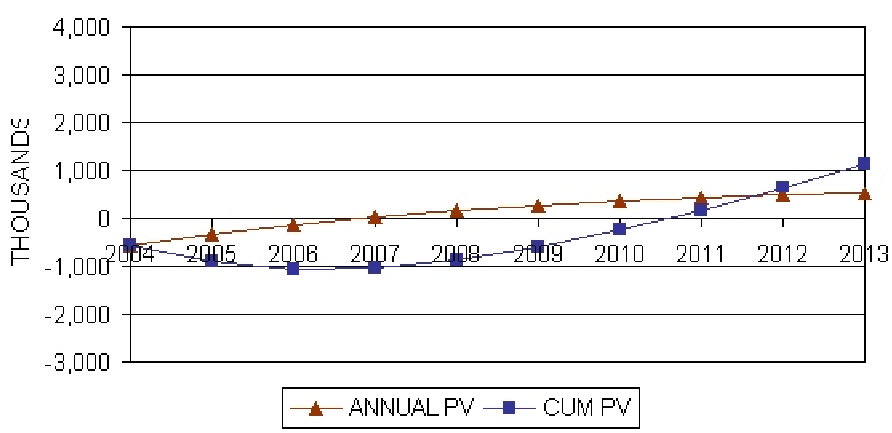


Fig. 9. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN COMMERCIAL LANDINGS OF VERMILION SNAPPER WITH A 12 INCH MINIMUM SIZE LIMIT

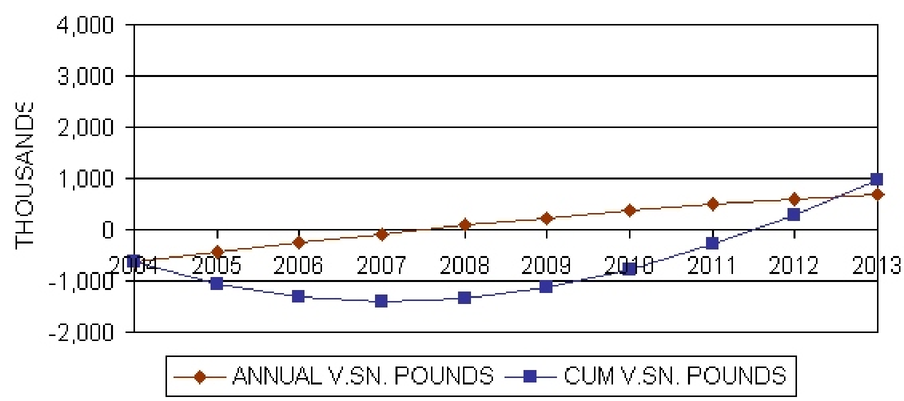
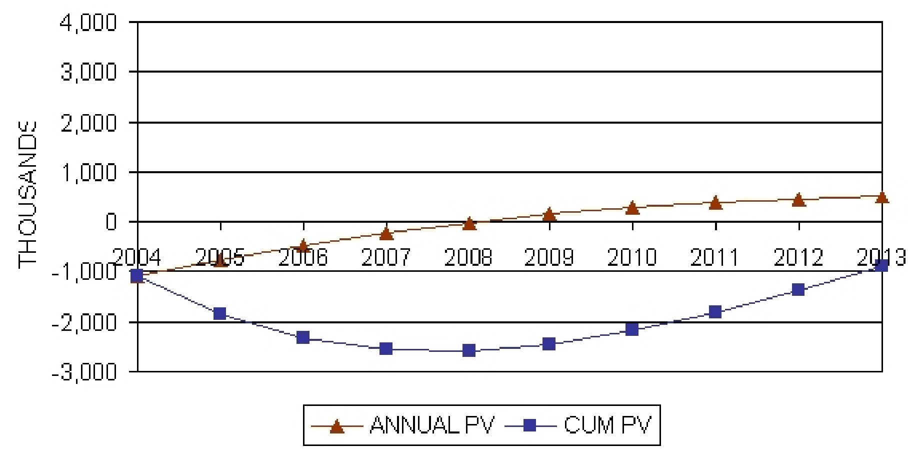


Fig. 10. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN PRESENT VALUE WITH A 12 INCH MINIMUM SIZE LIMIT



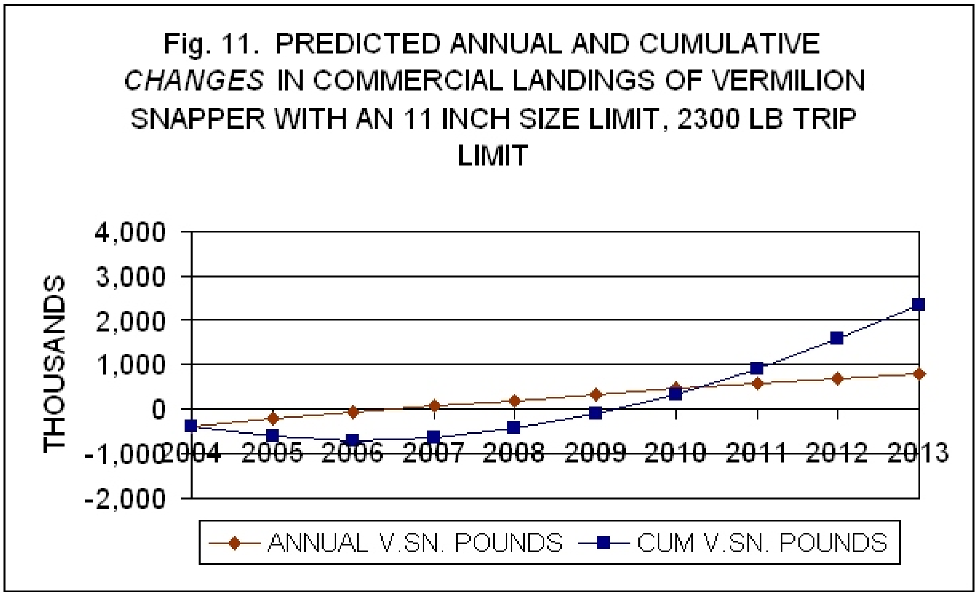


Fig. 11. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN COMMERCIAL LANDINGS OF VERMILION SNAPPER WITH AN 11 INCH SIZE LIMIT, 2300 LB TRIP LIMIT
THOUSANDS
4,000
3,000
2,000
1,000
0
-1,000
-2,000
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
ANNUAL V.SN. POUNDS
CUM V.SN. POUNDS

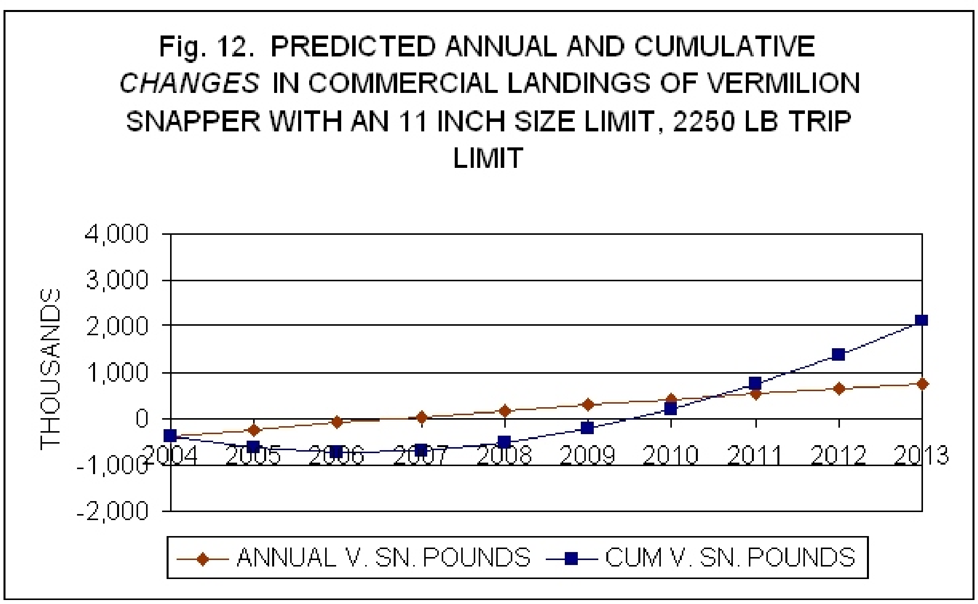


Fig. 12. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN COMMERCIAL LANDINGS OF VERMILION SNAPPER WITH AN 11 INCH SIZE LIMIT, 2250 LB TRIP LIMIT
THOUSANDS
4,000
3,000
2,000
1,000
0
-1,000
-2,000
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
ANNUAL V. SN. POUNDS
CUM V. SN. POUNDS

Fig. 13. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN PRESENT VALUE WITH AN 11 INCH SIZE LIMIT, 2300 LB TRIP LIMIT

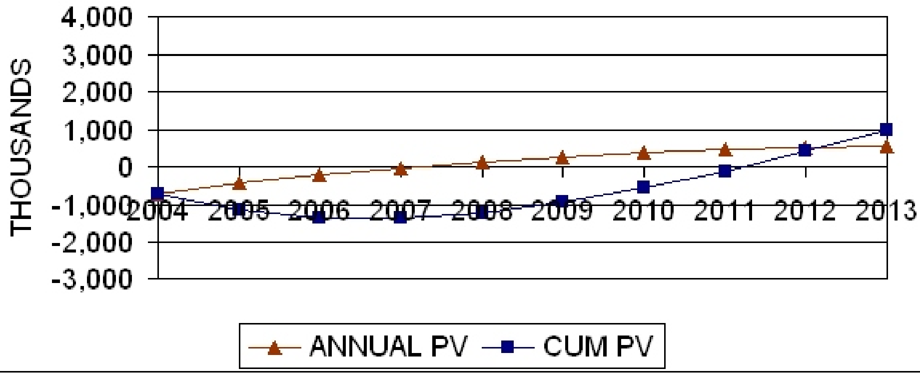
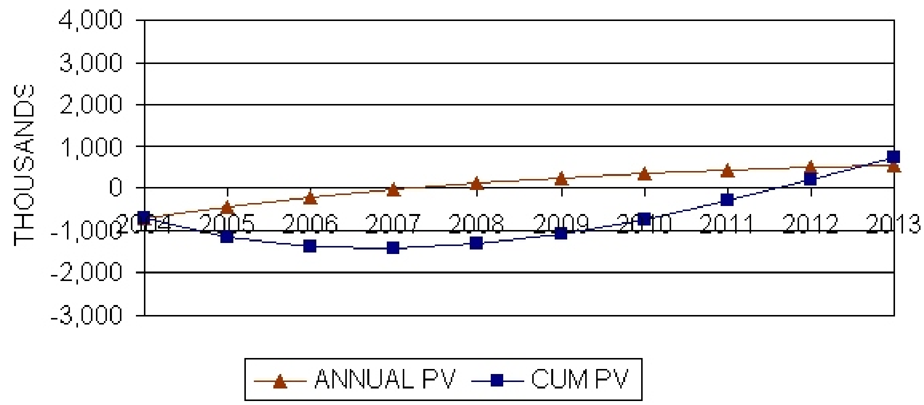


Fig. 14. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN PRESENT VALUE WITH AN 11 INCH SIZE LIMIT, 2250 LB TRIP LIMIT



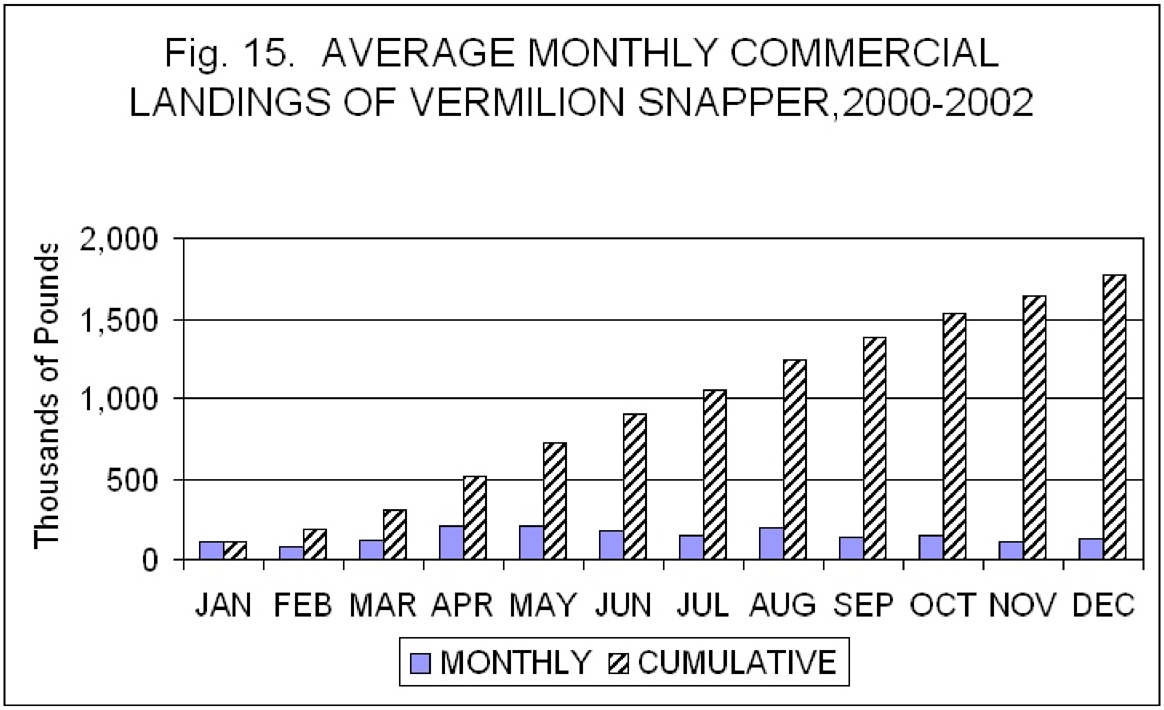


Fig. 15. AVERAGE MONTHLY COMMERCIAL LANDINGS OF VERMILION SNAPPER,2000-2002
Thousands of Pounds
2,000
1,500
1,000
500
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTHLY
CUMULATIVE

Fig. 16. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN COMMERCIAL LANDINGS OF VERMILION SNAPPER WITH PROPOSED QUOTAS

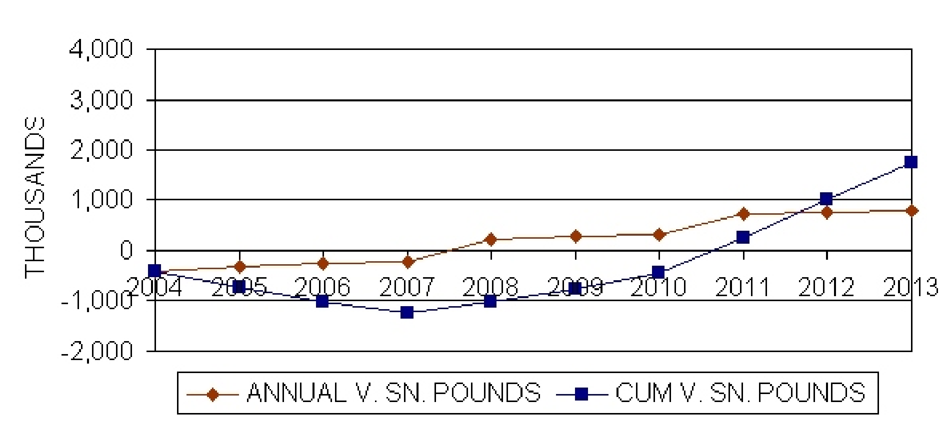


Fig. 17. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN PRESENT VALUE WITH PROPOSED QUOTAS

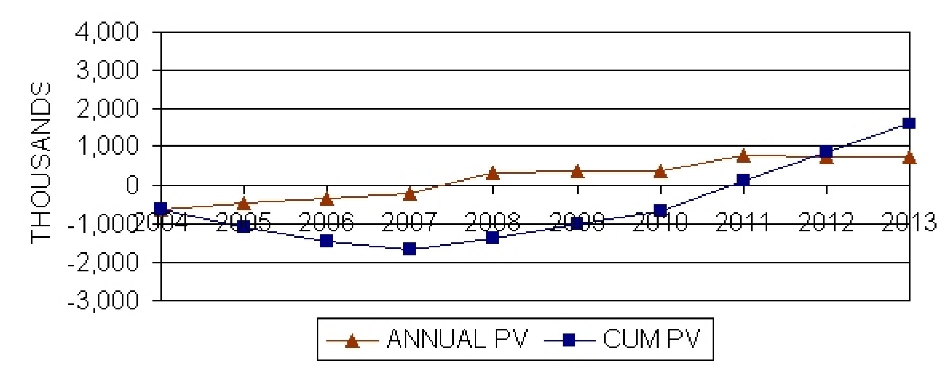


Fig. 18. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN COMMERCIAL LANDINGS OF VERMILION SNAPPER WITH CLOSED SEASON

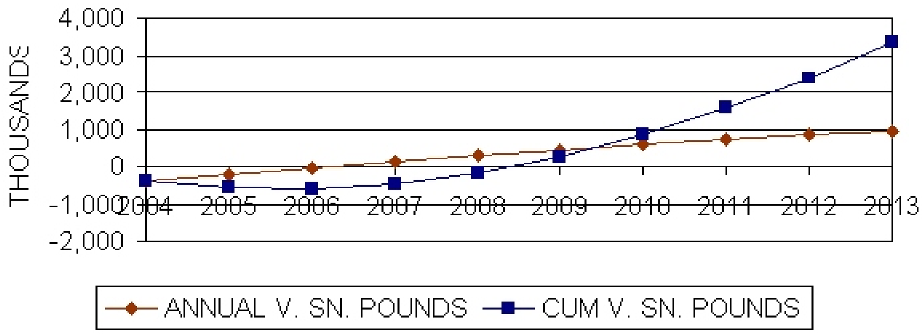
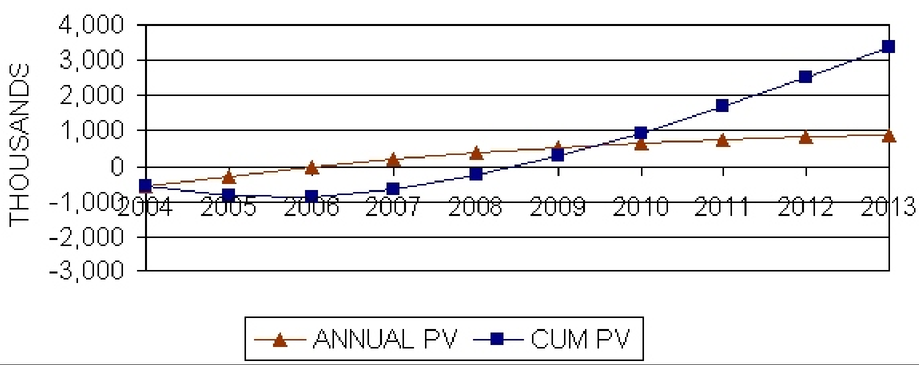


Fig. 19. PREDICTED ANNUAL AND CUMULATIVE *CHANGES* IN PRESENT VALUE WITH PROPOSED CLOSED SEASON



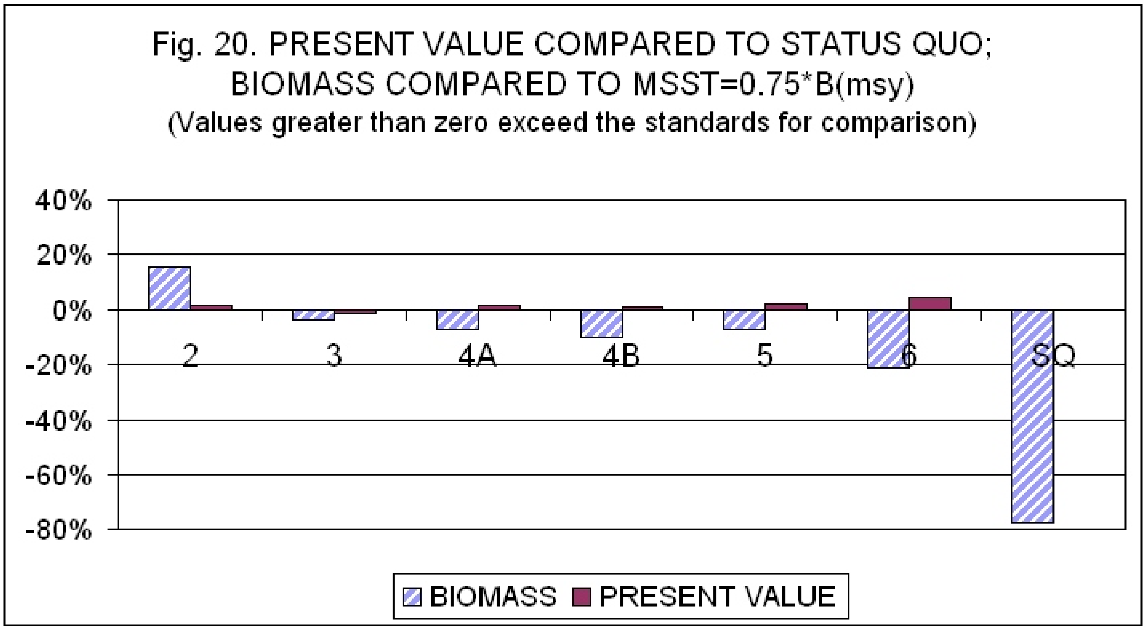


Fig. 20. PRESENT VALUE COMPARED TO STATUS QUO;
BIOMASS COMPARED TO MSST=0.75*B(msy)
(Values greater than zero exceed the standards for comparison)
40%
20%
0%
-20%
-40%
-60%
-80%
2
3
4A
4B
5
6
SQ
BIOMASS
PRESENT VALUE

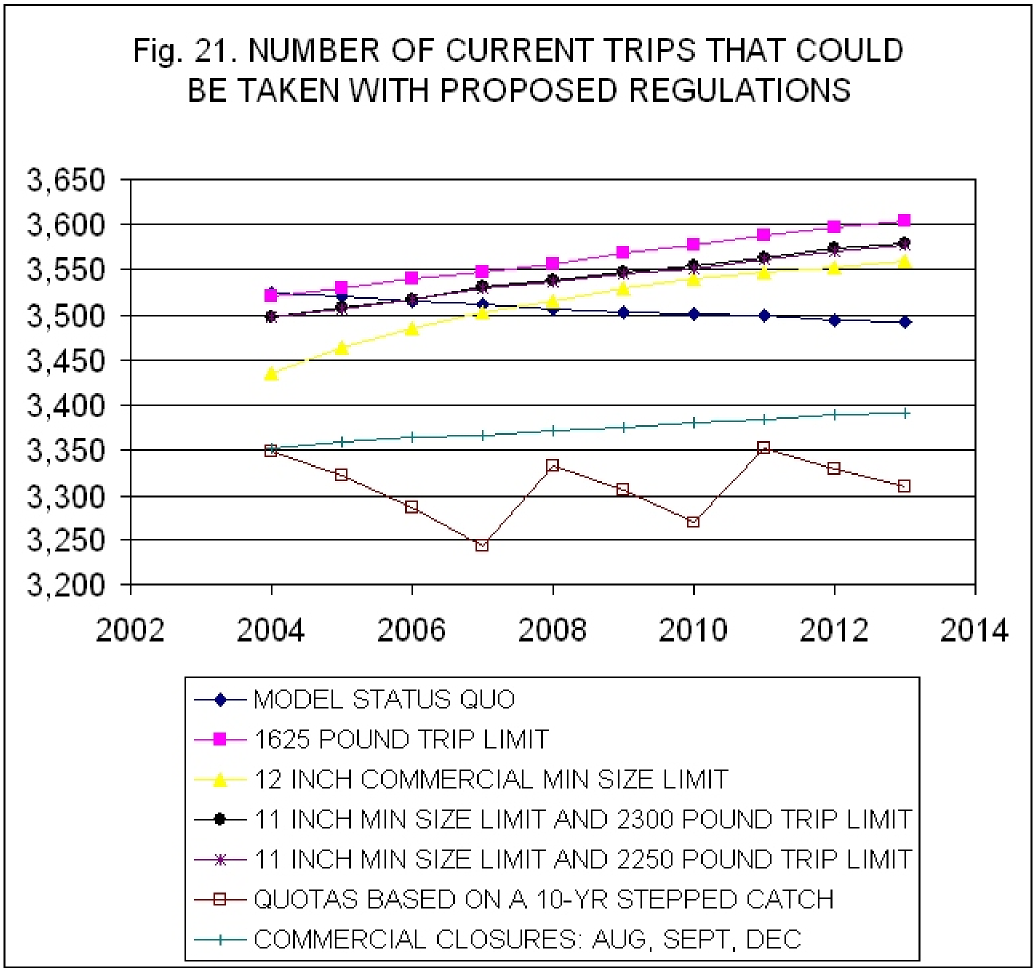


Fig. 21. NUMBER OF CURRENT TRIPS THAT COULD BE TAKEN WITH PROPOSED REGULATIONS
3,650
3,600
3,550
3,500
3,450
3,400
3,350
3,300
3,250
3,200
2002
2004
2006
2008
2010
2012
2014
MODEL STATUS QUO
1625 POUND TRIP LIMIT
12 INCH COMMERCIAL MIN SIZE LIMIT
11 INCH MIN SIZE LIMIT AND 2300 POUND TRIP LIMIT
11 INCH MIN SIZE LIMIT AND 2250 POUND TRIP LIMIT
QUOTAS BASED ON A 10-YR STEPPED CATCH
COMMERCIAL CLOSURES: AUG, SEPT, DEC

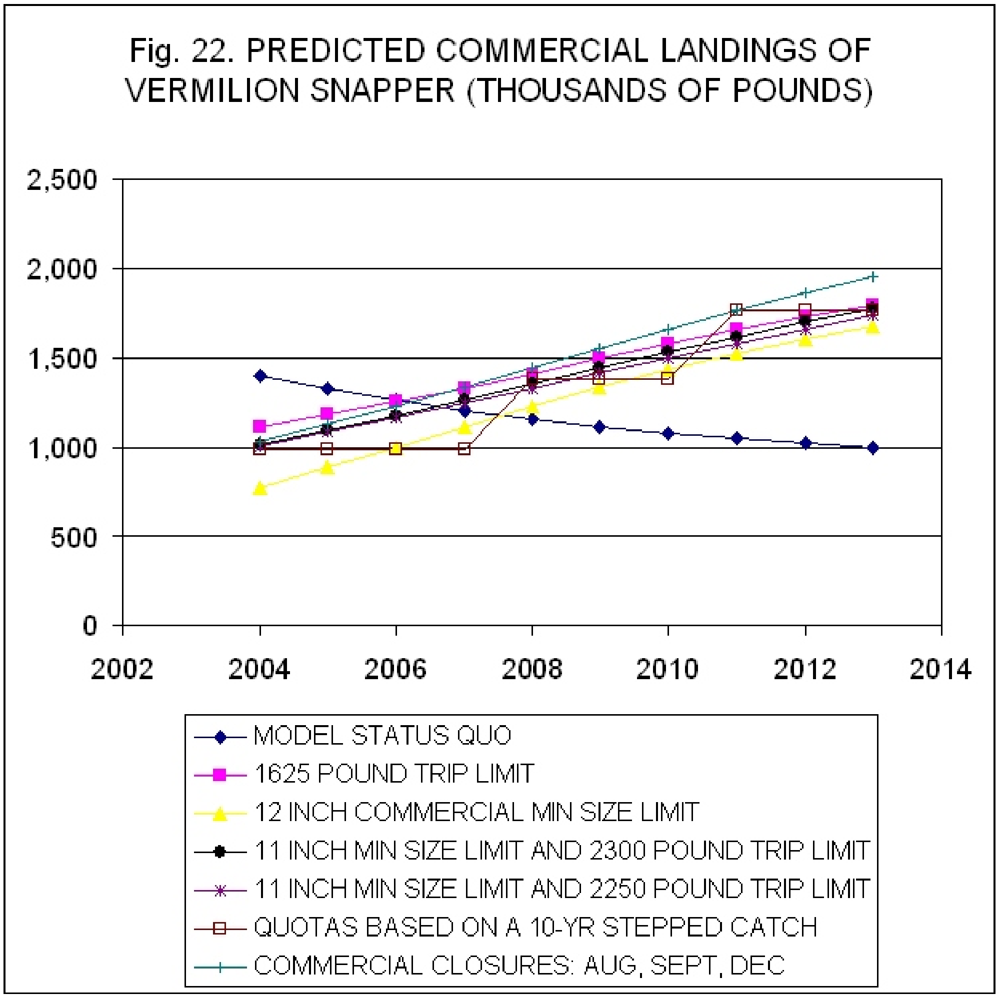


Fig. 22. PREDICTED COMMERCIAL LANDINGS OF VERMILION SNAPPER (THOUSANDS OF POUNDS)
2,500
2,000
1,500
1,000
500
0
2002
2004
2006
2008
2010
2012
2014
MODEL STATUS QUO
1625 POUND TRIP LIMIT
12 INCH COMMERCIAL MIN SIZE LIMIT
11 INCH MIN SIZE LIMIT AND 2300 POUND TRIP LIMIT
11 INCH MIN SIZE LIMIT AND 2250 POUND TRIP LIMIT
QUOTAS BASED ON A 10-YR STEPPED CATCH
COMMERCIAL CLOSURES: AUG, SEPT, DEC

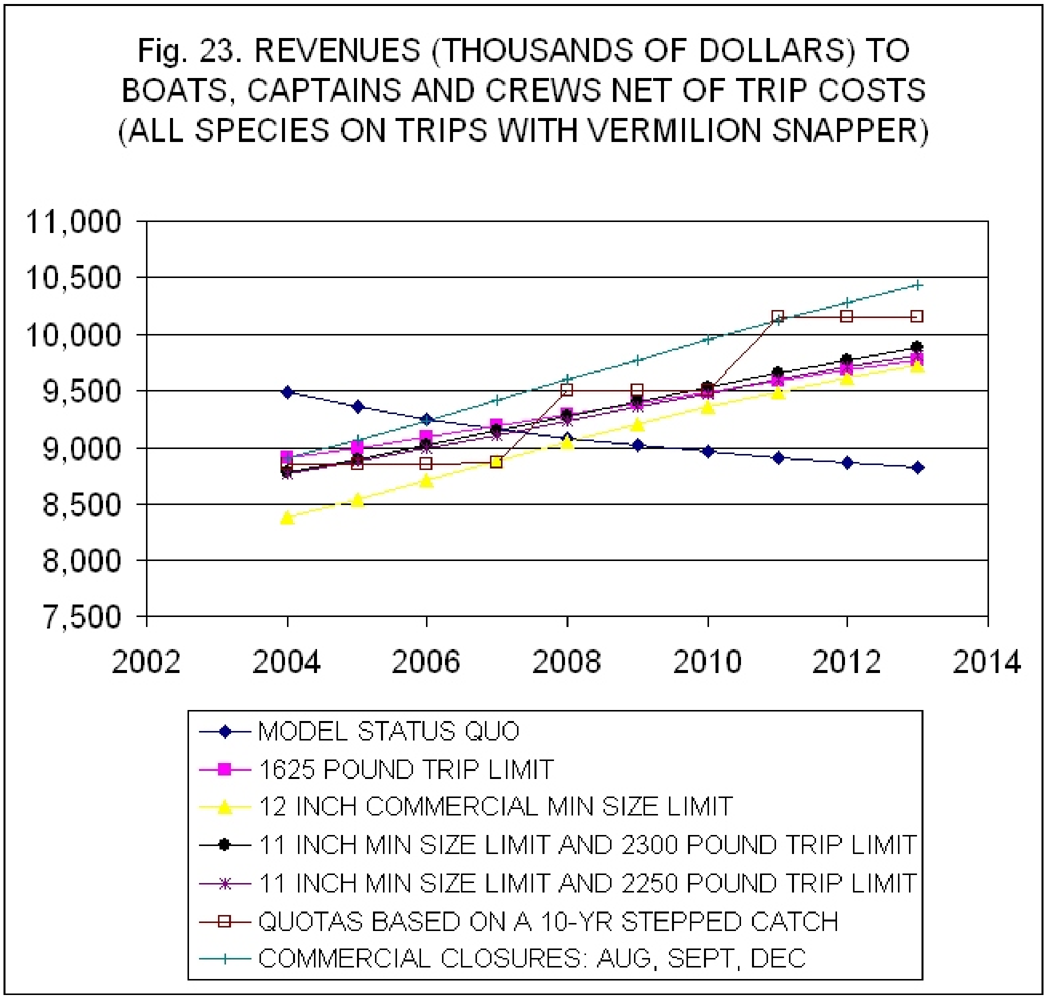


Fig. 23. REVENUES (THOUSANDS OF DOLLARS) TO BOATS, CAPTAINS AND CREWS NET OF TRIP COSTS (ALL SPECIES ON TRIPS WITH VERMILION SNAPPER)
11,000
10,500
10,000
9,500
9,000
8,500
8,000
7,500
2002
2004
2006
2008
2010
2012
2014
MODEL STATUS QUO
1625 POUND TRIP LIMIT
12 INCH COMMERCIAL MIN SIZE LIMIT
11 INCH MIN SIZE LIMIT AND 2300 POUND TRIP LIMIT
11 INCH MIN SIZE LIMIT AND 2250 POUND TRIP LIMIT
QUOTAS BASED ON A 10-YR STEPPED CATCH
COMMERCIAL CLOSURES: AUG, SEPT, DEC

Fig. 24. PRESENT VALUE OF REVENUES ($1000s) TO BOATS, CAPTAINS AND CREWS NET OF TRIP COSTS (ALL SPECIES ON TRIPS WITH VERMILION SNAPPER)

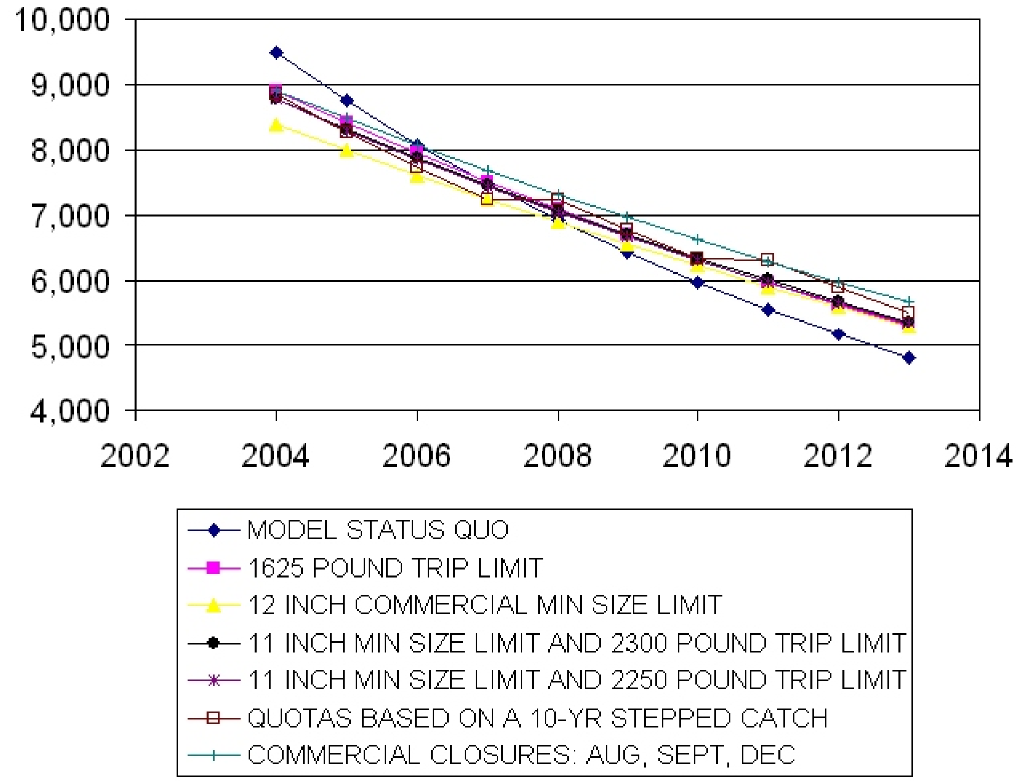
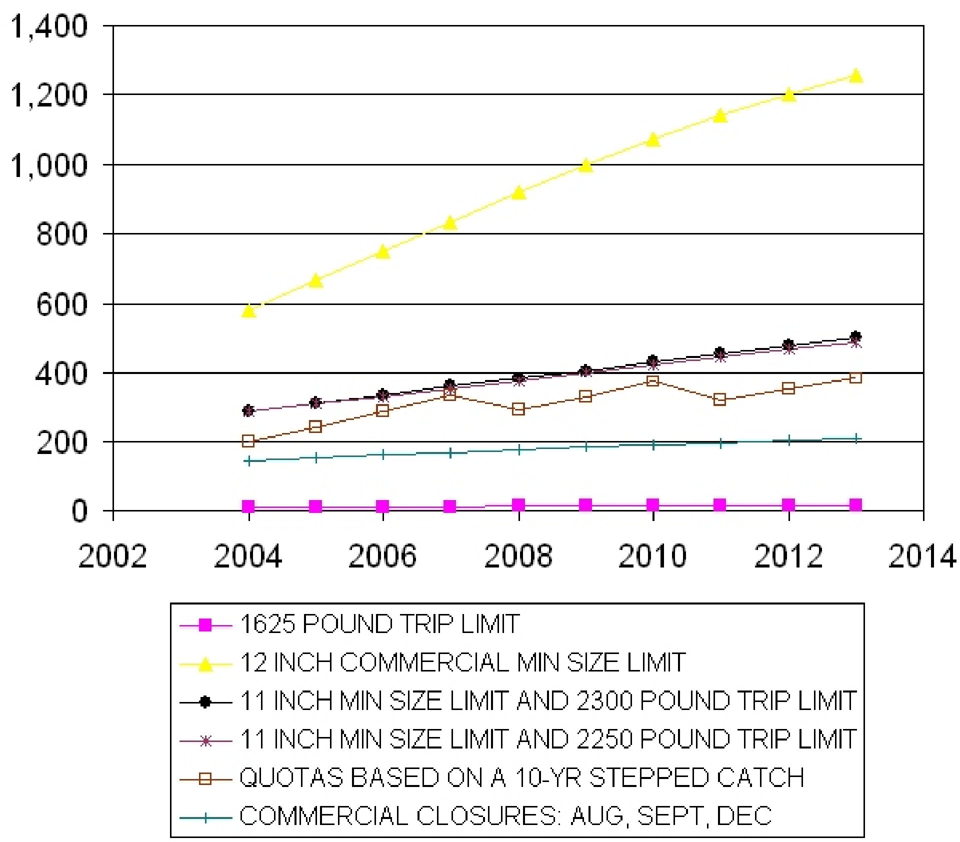


Fig. 25. PREDICTED COMMERCIAL DISCARDS OF VERMILION SNAPPER (THOUSANDS OF POUNDS)



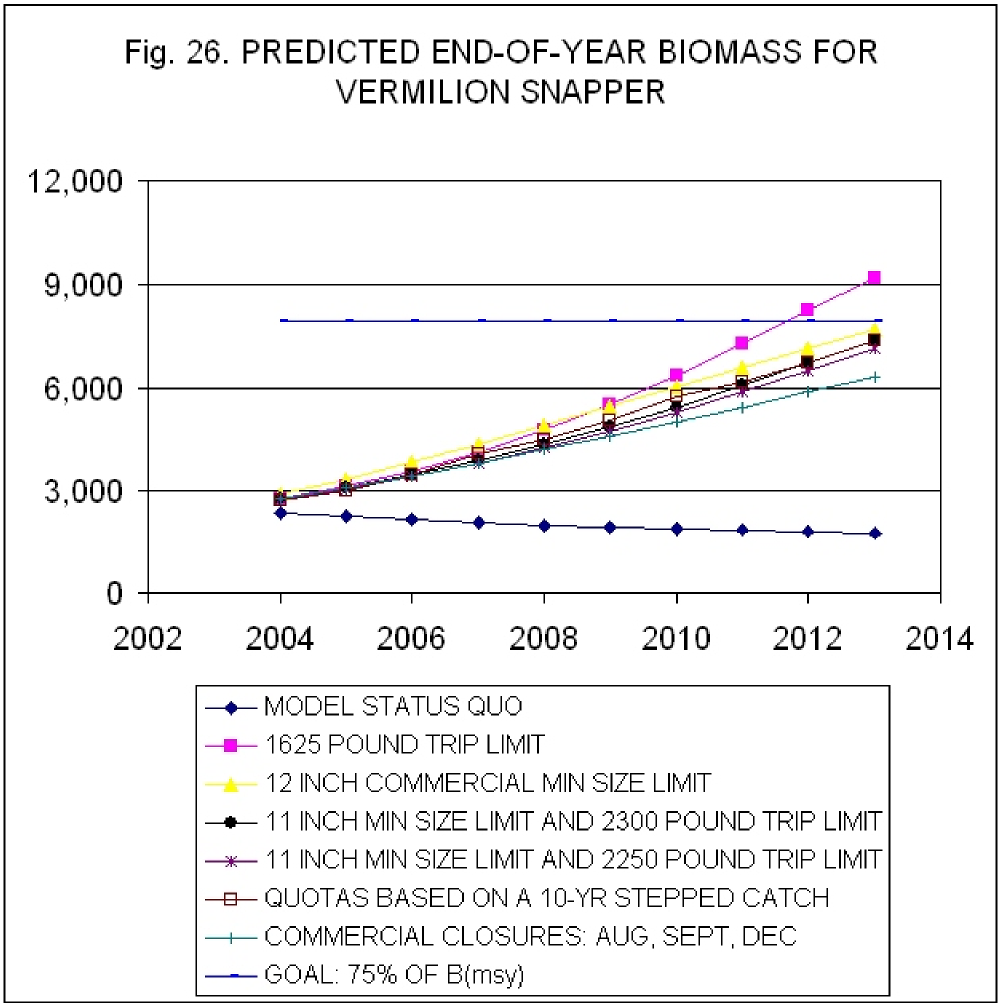


Fig. 26. PREDICTED END-OF-YEAR BIOMASS FOR VERMILION SNAPPER
12,000
9,000
6,000
3,000
0
2002
2004
2006
2008
2010
2012
2014
MODEL STATUS QUO
1625 POUND TRIP LIMIT
12 INCH COMMERCIAL MIN SIZE LIMIT
11 INCH MIN SIZE LIMIT AND 2300 POUND TRIP LIMIT
11 INCH MIN SIZE LIMIT AND 2250 POUND TRIP LIMIT
QUOTAS BASED ON A 10-YR STEPPED CATCH
COMMERCIAL CLOSURES: AUG, SEPT, DEC
GOAL: 75% OF B(msy)